JOURNAL

OF THE

AMERICAN SOCIETY OF AGRONOMY

VOLUME 14

1922

PUBLISHED BY THE SOCIETY

J B. LYON COMPANY, PRINTERS, ALBANY, N. Y.

Swanson and Tague (14) reported about one third of the nitrogen in good alfalfa silage and as much as half in bad alfalfa silage in amino form. They made the determinations of amino nitrogen by the formol-titration method and found a comparison of the titration figures for acidity and amino nitrogen to give an indication of quality. In good silage the figure for acidity was always larger than the figure for amino nitrogen, the difference being g ... .

That the amount of amino nitrogen var ... in-dicated in a later paper by the same auth ... t to be notably less in sweet clover silage tha ... ter (7) demonstrated the protein-sparing eff... ... ... ple-ments to alfalfa silage. When an available carbohydrate was added, the acid content was increased and the amino nitrogen decreased. In view of this evidence and the fact that in general the presence of acid tends to inhibit proteolytic fermentation, excessive protein decomposition in crops or mixtures containing a sufficient supply of utilizable carbohydrates would not be expected. The existence of a large proportion of the nitrogen in amino form would suggest that the acid content had been destroyed by molds, due to incomplete exclusion of air.

CHEMICAL EXAMINATION OF SAMPLES.

The samples of portions *A* and *B*, taken when the barrels were opened, were analyzed the same day for moisture, total acidity, volatile acidity, and amino nitrogen. The total nitrogen was determined later, using the residues from the moisture determinations. Samples from the farm silo were analyzed for comparison. This silo had been filled with alternate layers of corn and a mixture of peas and oats, a few loads, varying in number, in each layer.

Moisture Content.—Duplicate samples of 100 grams of silage were dried to approximately constant weight in an electric oven at 100° to 103° C.

Preparation of Water Extract.—Water extracts were made by placing 100-gram samples in quart jars, with 425 c.c. distilled water. All distilled water used for extractions and dilutions thruout the work was freshly boiled to free it from carbon dioxid. The jars were shaken in a shaking machine 2½ hours and the contents filtered. A portion of 25 c.c. extract was approximately equal to 5 grams of silage, but necessary corrections were made later from the figures obtained in the moisture determinations. A comparison of buckwheat silage juice, as drained out of the barrel, with water extract prepared as above, on the basis of an equivalent quantity of silage, showed

practically the same amounts of acid and amino nitrogen in each. The necessity of completing the determinations on the water extract at once was proved by the fact that the following morning the portion remaining in the laboratory was invariably covered with a scum. When it was desired to make further studies of the extract, it was sterilized without appreciable loss by boiling gently under an inverted condenser.

Total Acidity.—Duplicate portions of 25 c.c. extract were pipetted into 500 c.c. erlenmeyers, diluted with 200 c.c. water, and titrated with .05 normal sodium hydroxid, using phenolphthalein as an indicator.

Volatile Acidity.—A portion of 100 c.c. extract was measured into a 500 c.c. distilling flask, the graduate then being washed with 20 c.c. water from a pipette and the washings added to the contents of the flask. The dimensions of the distilling apparatus and the time of distillation were kept uniform thruout, 80 c.c. of distillate being collected in about 30 minutes. The residue and distillate were both made up to 100 c.c. and duplicate portions of 25 c.c. titrated. The slight loss which usually occurred in distillation was added to the volatile acid. The total amount of volatile acid was calculated from Duclaux' constants as published by Dox and Neidig (2). For this purpose it was assumed that the volatile acid was 90 percent acetic and 10 percent propionic.

The above method of determining volatile acidity, while probably not as exact as steam distillation under reduced pressure, is much more quickly done, and was considered sufficiently accurate for the purpose of estimating the quality of silage. The slight volatility of lactic acid at 100° C. would hardly lead to appreciable error. Dox and Neidig (2) quote Jensen as authority for the statement that 5 percent of the lactic acid passes over with the distillate when a dilute solution is reduced to one eleventh of its original volume. The boiling point of the silage extracts at the latter concentration was experimentally determined to be about 118° C., whereas it increased comparatively little up to the point to which the distillations were carried in the present study. The initial boiling point was about 98.5° C. at this altitude. It reached 100° C. when about 65 c.c. had passed over, and 103.5° C. when 80 c.c. (the amount used) had been collected. Beyond this point it increased rapidly.

Amino Nitrogen.—The amino nitrogen was determined by titration, using this method as described by Plimmer (11), with small modifications. The same portions of extract which had been titrated for total acidity were used at once for this determination. After adding 25 c.c. of dilute neutral formaldehyde, the portions were allowed to

stand 15 minutes, and then retitrated with .05 normal sodium hydroxide.

Total Nitrogen.—The total nitrogen was determined by the official Kjeldahl method, using the residues from the moisture determinations.

The results of the chemical examination of the samples are given in Table 2. For comparison, an estimate of the quality of the samples, as judged by appearance and odor at time of sampling, is included.

DISCUSSION OF TABLE 2.

The moisture content of the corn and sunflowers, both singly and mixed, was very high, but did not appear to exercise a detrimental effect. It did not correspond to a proportional development of acidity. In fact, the acidity of portion *B* of each barrel was greater than that of portion *A*, tho the latter in every case contained more moisture.

The percentage of total acid is expressed on the basis of silage (column 4) and dry matter (column 12), as some of the authors cited use the latter method. In the poorer samples the total acidity was proportional to the quality as judged by appearance and odor at the time of sampling, but among the good samples there was considerable variation. As already noted, however, taking each barrel individually, the total acidity was greater in portion *B*, the better part of the barrel. The samples from the farm silo had a much greater acidity than the others on the basis of silage, but not on the dry matter basis. They did not appear to be superior in any respect to similar material from the barrels.

The ratio of nonvolatile to volatile acidity was largest in the best samples and smallest in the poorest. In all samples the quality as judged by this ratio agreed very closely with the estimate at sampling.

The total acidity is repeated in column 8, placed beside the column for amino nitrogen, both expressed as cubic centimeters .05 normal in 5 grams silage, to facilitate the comparison suggested by Swanson and Tague (14). In all cases the figures for acidity are much larger than those for amino nitrogen, the difference being greatest in the best samples.

The ratio of amino nitrogen to total nitrogen, however, did not vary as might have been expected from the foregoing estimates of the quality of the samples. The proportion of amino nitrogen tended rather to increase in the better silage. The cause of this was not investigated, but it should be remembered that the authors just cited worked with alfalfa as silage material, while the materials used in this experiment were relatively very poor in nitrogen, as shown by the last column of the table.

TABLE 2.—*Chemical analysis of silage stored in barrels.*

Sample.	Quality as judged by appearance and odor.	Moisture.	Total acid.	Nonvolatile acid as lactic.	Volatile acid as acetic.	Ratio of nonvolatile to volatile acid.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Corn:						
A	90	88.30	1.413	0.999	0.414	1 : 0.41
B	100	86.65	1.803	1.359	.444	1 : 0.33
Sunflowers:						
A	80	85.55	1.029	.621	.408	1 : 0.66
B	100	83.70	1.347	.909	.438	1 : 0.48
Corn and sunflowers:						
A	50	85.45	.141	.045	.096	1 : 2.13
B	95	83.65	1.182	.756	.426	1 : 0.56
Oats:						
A	90	70.85	.729	.513	.216	1 : 0.42
B	100	70.40	1.284	.882	.402	1 : 0.46
Buckwheat:						
A	70	77.90	.666	.306	.360	1 : 1.18
B	100	78.80	.786	.522	.264	1 : 0.51
Juice[a]		95.90	.705	.459	.246	1 : 0.54
Farm silo:						
Corn	100	75.45	2.718	1.872	.846	1 : 0.45
Peas and oats	100	67.10	2.118	1.404	.714	1 : 0.51

Sample.	Total acidity in 5 grams silage.	Amino nitrogen in 5 grams silage.	Total nitrogen in 5 grams silage.	Ratio of amino to total nitrogen.	Total acid per 100 grams dry matter.	Total nitrogen in dry matter.
	C c. $\frac{1}{20}$ *N.*	*C.c.* $\frac{1}{20}$ *N.*	*C.c.* $\frac{1}{20}$ *N.*		*Grams.*	*Per cent*
Corn:						
A	18.0	2.0	10.9	1 : 5.45	12.08	1.31
B	22.5	3.6	12.6	1 : 3.50	13.51	1.32
Sunflowers:						
A	13.7	1.2	14.9	1 : 12.42	7.12	1.44
B	17.4	1.9	13.4	1 : 7.05	8.26	1.15
Corn and sunflowers:						
A	2.1	0.8	17.3	1 : 21.63	.99	1.67
B	15.5	2.1	15.5	1 : 7.38	7.23	1.33
Oats:						
A	9.3	6.7	30.6	1 : 4.57	2.50	1.47
B	16.5	9.3	31.7	1 : 3.41	4.34	1.50
Buckwheat:						
A	9.4	3.7	31.7	1 : 8.57	3.01	2.01
B	10.2	4.2	30.6	1 : 7.29	3.71	2.02
Juice[a]	9.2	3.7				
Farm silo:						
Corn	34.9	10.4	37.7	1 : 3.63	11.07	2.15
Peas and oats	27.5	8.8	32.0	1 : 3.64	6.44	1.36

[a] Figures, except for moisture, are calculated for equivalent quantities of silage.

SUMMARY.

The results of this preliminary experiment indicate that barrels are quite suitable as experimental containers for silage. The quality of the silage produced was judged by appearance, odor, palatability, and the various chemical tests suggested by the literature on the subject.

In comparison with published results of similar tests and with samples taken at the same time from an ordinary farm silo, the material from the barrels was considered to be in all important respects normal silage.

LITERATURE CITED.

1. BECHDEL, S. I. Studies in the preservation of corn silage. *In* Pa. Agr. Expt. Sta. Ann. Rpt. 1915/16, pp. 323 348. 1917.
2 DOX, A. W., and NEIDIG, R. E. The volatile aliphatic acids of corn silage. Iowa Agr. Expt. Sta. Research Bul. 7. 1912.
3 ——. Lactic acid in corn silage. Iowa Agr. Expt. Sta. Research Bul. 10. 1913.
4. ECKLES, C. H. Legumes, Sudan grass and cereal crops for silage. Mo. Agr. Expt. Sta. Bul. 162. 1919.
5. ——, OSHEL, O. I., and MAGRUDER, D. M. Silage investigations: Normal temperatures and some factors influencing the quality of silage. Mo. Agr. Expt. Sta. Research Bul. 22. 1916.
6. HENRY, W. A., and MORRISON, F. B. Feeds and Feeding, 16th ed. Authors, Madison, Wis. 1916.
7. HUNTER, O. W. Bacteriological studies on alfalfa silage. *In* Jour. Agr. Research, v. 15, no. 11, p. 571-592. 1918.
8. LAMB, A. R. The relative influence of microorganisms and plant enzyms on corn silage fermentation. Iowa Agr. Expt. Sta. Research Bul. 40. 1917.
9. NEIDIG, R. E. Chemical changes during silage formation. Iowa Agr. Expt. Sta. Research Bul. 16. 1914.
10. ——. Acidity of silage made from various crops. *In* Jour. Agr. Research, v. 14, no. 10, p. 395–409. 1918.
11. PLIMMER, R. H. A. Practical Organic and Bio-chemistry, revised ed. Longmans, Green and Co., London. 1918.
12. REED, O. E., and FITCH, J. B. Alfalfa silage. Kans. Agr. Expt. Sta. Bul. 217. 1917.
13. SAMARANI, F. The preparation of ensilage. *In* Bollettino del Ministero di Agricultura, Industria e Commercio, year 13, nos. 8–12, p. 87–103. Rome, 1913. (*Abs. in* Bul. Foreign Agr. Intell., v. 5, no. 3, p. 206–207. Ottawa, 1915.)
14. SWANSON, C. O., and TAGUE, E. L. Chemical studies in making alfalfa silage. *In* Jour. Agr. Research, v. 10, no. 6, p. 275–292. 1917.
15. ——. Chemistry of sweet clover silage in comparison with alfalfa silage. *In* Jour. Agr. Research, v. 15, no. 2, p. 113–132. 1918.
16. WESTOVER, H. L., and GARVER, S. A cheap and convenient experimental silo. *In* Jour. Amer. Soc. Agron., v. 12, no. 2, p. 69–72. 1920.

THE RELATION OF FERTILIZERS TO HESSIAN FLY INJURY AND WINTERKILLING OF WHEAT.[1]

W. B. ELLETT AND T. K. WOLFE.[2]

The damage to wheat from Hessian fly injury and winterkilling in the southwestern portion of Virginia during the past season was unusually severe. The early fall was dry, followed by damp, warm weather until about November 1. As a result wheat, even when seeded at what was ordinarily the proper date, suffered heavily from attacks of the Hessian fly. The winter temperature was comparatively mild, but with frequent and rapid fluctuations, while the snowfall was unusually light. As a consequence, much wheat winterkilled.

In order to obtain data with regard to the winter injury and Hessian fly damage, notes were taken on some of the wheat experimental plats at Blacksburg. The data presented in Table 1 were taken from plats which have been growing wheat continuously since 1908. The treatments shown have been made annually just previous to seeding the wheat, with the exception of the manure, which has been applied during the winter. The plats are one twentieth of an acre each. In making the counts on Hessian fly injury, the total number and the number of lodged stalks were counted in ten rows on each of the plats. All stalks were not examined for the fly injury; only those stalks which had lodged at the time of counting were classed as injured by the fly. The counts were made just before the wheat matured. In addition to the counts, Table 1 also shows the yields from the various plats. The yields suggest the degree of winterkilling.

The data presented in Table 2 were obtained from a rotation experiment with fertilizers started in 1909. The rotation consists of corn, wheat, and grass and clover two years. The treatments shown are made annually except where noted otherwise in the table. During the first five years of the experiment the applications of commercial fertilizers were half the amounts as now given. The applications of manure have been the same since the experiment was started. The degree of winterkilling is indicated by the yields.

[1] Contribution from the Virginia Agricultural Experiment Station, Blacksburg, Va. Received for publication August 12, 1920.

[2] Chemist and associate agronomist, respectively, at the Virginia Agricultural Experiment Station.

In Table 1 data are presented in regard to Hessian fly injury and winterkilling of wheat grown under continuous cropping conditions.

TABLE 1.—*The effect of fertilizers on Hessian fly injury and winterkilling of wheat.*

Plat No.	Treatment.	No. of stalks. Not lodged.	Lodged.	Percentage of stalks lodged.	Yield of grain, bushels per acre.
1	Manure 10 tons, acid phosphate 321 lbs.	4,096	206	4.79	16.75
2	Acid phosphate 321 lbs.	1,308	248	15.94	3.00
3	Manure 10 tons, floats 200 lbs., lime 1,200 lbs.	5,574	728	11.55	24.83
4	Floats 200 lbs.	451	169	27.26	.92
5	Check	356	95	21.06	[b]
6	Manure 10 tons, floats 200 lbs.	3,636	436	10.71	16.83
7	Manure 10 tons	3,503	417	10.64	14.17
8	Buckwheat turned under, floats 200 lbs.[a]				[b]
9	Check[a]				[b]
10	Buckwheat turned under, floats 200 lbs., lime 1,200 lbs.	839	342	28.96	2.00
11	Buckwheat turned under[a]				[b]
12	Buckwheat turned under, acid phosphate 321 lbs., lime 1,200 lbs.	2,016	642	24.15	4.83
13	Check	351	107	23.36	.75

[a] No counts made because of small number of plants.
[b] No yield obtained because of small number of plants.

It will be seen from Table 1 that when acid phosphate or manure has been used that the Hessian fly injury is smaller and the yield greater than when manure has not been used or when floats has been applied in place of acid phosphate. The fly injury ranges from 4.79 percent in the manure-acid-phosphate plat to 28.96 percent in the buckwheat-floats-lime plat. The manure plat suffered 10.64 percent fly injury, which is next to the lowest.

In Table 2 data are presented in regard to winterkilling as shown by yields secured from a rotation experiment with fertilizers in which corn, wheat, and grass were grown.

TABLE 2.—*Effect of fertilizers on winterkilling of wheat as shown by yields.*

Treatments.	Grain, bushels per acre.	Increase over check, bushels.
Check	0.33	
438 lbs. acid phosphate	5.40	5.07
Check	.53	
308 lbs. dried blood, 438 lbs. acid phosphate, 200 lbs. muriate potash	9.53	9.00

Check	1.53	
438 lbs. acid phosphate, 200 lbs. [illegible]	[illegible]60	7.07
Check	[illegible]0	
308 lbs. dried blood, 200 lbs. muriate potash	1.33	.33
Check	.40	
308 lbs. dried blood, 438 lbs. acid phosphate	7.53	7.13
Check	.53	
16 tons manure once in four years before corn	18.40	17.87
Check	3.20	
4 tons manure annually	18.33	15.13
Check	1.00	
16 tons manure once in four years before corn, 438 lbs acid phosphate annually	22.13	21.13
Check	.53	
218 lbs. floats	2.80	2.27

It will be noted from Table 2 that manure has markedly prevented winterkilling, as shown by the yields. The results are also striking in that they indicate the element most needed to increase yield and decrease the amount of winterkilling is phosphorus. In this regard acid phosphate has been more satisfactory than floats. Under the conditions of this test it seems that phosphorus was the most important plant nutrient.

Practically all the soils of Virginia are markedly deficient in phosphorus and that plant nutrient must be supplied before material increases in yield can be secured. On many of the soils of the State the organic matter content is low and this in addition to phosphorus must be increased to secure larger crop yields. Thus it seems that phosphorus, unless supplied by commercial fertilizer, is nearly always the limiting factor in crop production in Virginia, while often both phosphorus and organic matter limit crop yields.

Of the materials used those which have increased crop yields and lessened the Hessian fly injury and winterkilling in Virginia to the greatest extent have been stable manure and acid phosphate.

INHERITANCE OF DISEASE [illegible] BEAN.[1]

G. P. McRostie.[2]

Scope of the Paper.

The data and discussions recorded in this paper represent the results of over three years' observations on the mode of inheritance in the common bean, *Phaseolus vulgaris,* of the factors concerned in the production of resistance to three common bean diseases of New York. The data were obtained mostly from material grown in connection with the New York bean investigations with which the writer was connected in the capacity of plant breeder.

A short resume is included of the literature pertaining to the mode of inheritance of the factors responsible for disease resistance. No attempt has been made to include a complete bibliography of this subject, but enough data have been included to indicate the diversity of results that may be expected when working with different diseases.

Previous Results on the Inheritance of Disease Resistance.

The definite inheritance of disease resistance has been studied largely in late years and even yet the literature on the subject is decidedly limited. Biffen (3)[3] found that resistance to the yellow rust, *Puccinia glumarum* Eriks. and Henn., in his cross between Rivet, a slightly susceptible wheat, and Red King, an extremely susceptible one, behaved as a recessive, all the F_1 plants and approximately 75 percent of the F_2 plants having been susceptible. Nilsson-Ehle (7), in crosses between wheats resistant to yellow rust and varieties susceptible to this disease, found susceptibility dominant in the F_1 and was of the opinion that a multiple-factor explanation of the genetic behavior of resistance was the correct one in his crosses. Vavilov (13), in crosses between Persian wheat, *Triticum vulgare* var. *fuliginosum* Al., which was immune to mildew, *Erysiphe graminis* D. C.,

[1] Paper No. 81, Department of Plant Breeding, Cornell University, Ithaca, N. Y. Received for publication August 27, 1920.

[2] The writer wishes to acknowledge indebtedness for suggestion, assistance, and criticism to Dr. R. A. Emerson, Dr. D. Reddick, and Dr. M. F. Barrus. Appreciation is also expressed to Dr. W. H. Burkholder, who assisted with some of the inoculations and who also supplied a part of the cultures of the anthracnose fungus and all of those of the root-rot fungus.

[3] Reference is to "Literature cited," p. 32.

and varieties of common bread wheats susceptible to this disease, secured F_1 hybrids which were immune to the mildew. Stuckey (11), in breeding varieties of tomatoes resistant to blossom-end rot, found that resistance wa[illegible] character. Tisdale (12), studying the inheritance of flax wilt, in crosses between resistant and susceptible flax varieties, obtained a great variety of results grading all the way from F_1 generations that were wholly resistant to F_1 generations that were wholly susceptible. He attempts to explain his results on the basis of multiple factors, claiming that under normal conditions two or three factors in the homozygous condition would be enough to show apparent resistance. Under conditions exceptionally favorable for infection only those plants which had all factors concerned in the homozygous condition would show resistance. The gradation in the F_1 results might, therefore, be explained on the basis of severity of infection.

Burkholder (4), in crosses between Wells' Red Kidney, a type of bean resistant to both α and β strains of *Colletotrichum lindemuthianum*, and the White Marrow bean resistant to only the α strain (2), obtained in the F_2, out of a total of 473 plants tested, 362 which proved resistant and 111 which proved susceptible to this disease. These numbers show almost an exact 3:1 ratio and indicate a single factor difference between the resistant and susceptible plants with respect to the β strain of the anthracnose fungus concerned in the cross. McRostie (6), in crosses between Wells' Red Kidney and the White Pea bean resistant to the β strain of anthracnose, obtained a similar ratio. Out of a total of 1,970 second generation plants inoculated, 1,471 showed resistance and 499 susceptibility to this disease.

INVESTIGATIONS.

INHERITANCE OF RESISTANCE TO THE BEAN ANTHRACNOSE FUNGUS.

The data included in this section are additional facts obtained since the publication of the author's first paper on this subject (6). A short summary of this paper is given here to afford a better understanding of the tables and discussions which follow.

Two strains, α and β, of the anthracnose fungus, *Colletotrichum lindemuthianum* (Sacc. and Magn.) Bri. and Cav., are reported by Barrus (2), and the resistance and susceptibility to these strains of a large number of varities of beans is listed by him. The resistant parent used in the crosses reported in the previous article was a strain of bean (Wells' Red Kidney) which was resistant to both strains of the fungus. The susceptible parent used was the Michigan Robust

Pea bean which is susceptible to the α strain but resistant to the β strain of the fungus. Thus, [illegible] the α strain of the [illegible] producing organism was concerned in the [illegible] were inoculated, 1,471 showed resistance and 499 susceptibility to the disease under discussion. These results approximate closely a 3:1 ratio between resistance and susceptibility, with resistance dominant. This ratio is also borne out by the progenies of a number of second generation plants that were grown thru to the third generation before being inoculated. Approximately 25 percent of these third generation families bred true for resistance, 50 percent gave both resistant and susceptible plants, and approximately 25 percent bred true for susceptibility. The actual results by families were as follows: 9 homozygous resistant, 16 heterozygous resistant, and 11 susceptible.

The following tables present second generation results of plants grown and inoculated during the summer of 1919.

TABLE 1.—*Additional F_2 data (1919) on crosses involving the α strain of anthracnose.*

Pedigree No.	Parentage of hybrids.	Resistant.	Susceptible.
5480........	Wells' Red Kidney × Robust	216	85
5481........	Do.	66	16
5482........	Selection B × Robust	135	55
Totals........		417	156
Expected numbers........		429.75	143.25
Difference........		12.75 ± 6.99	

The parentage of the crosses reported in Table 1 is exactly the same, with one exception, as that of the hybrids spoken of in the included summary of the previous paper. This exception is the use of selection B as the resistant parent instead of Wells' Red Kidney. This selection was a White Marrow bean from one of the families mentioned in the summary as being homozygous resistant for anthracnose. The results obtained approach, within twice the probable error, a 3:1 ratio with resistance dominant which, in accord with previous results, indicates a single factor difference concerned in the production of resistance to the α strain of the anthracnose fungus.

The majority of the crosses listed in Table 2 were between selection B, which is resistant to both α and β strains of anthracnose, and two varieties of wax beans that are susceptible to both of these strains (2). Two families are also included in which one parent is resistant to only the α strain and the other parent to only the β strain of anthracnose. In all of these crosses, therefore, unlike the cases hereto-

TABLE 2.—*F_2 data (1919) on crosses in which both the α and β strains of the anthracnose fungus were presumed to be present.*

Pedigree No.	[illegible]	[illegible]	usceptible.	Total.
5471........	German \	[illegible]	29	42
5472........	Do.	26	38	64
5485........	Do.	32	27	59
5473........	Wardwell's Wax × Selection [illegible]	62	43	105
5474........	Do.	151	59	210
5486........	Do.	14	20	34
5557........	Do.	26	21	47
5558........	Do.	82	69	151
5483........	Robust × White Marrow	216	158	374
5484........	Do.	90	54	144
Totals of all plants..........		712	518	1,230
Expected numbers (9 : 7 ratio)............		692	538	
Difference...........................		20 ± 11.7		

fore reported, both strains of anthracnose were presumed to be involved.

Since the earlier results indicated that a single pair of genetic factors is concerned where either the α or β strain is alone involved, a 9:7 F_2 ratio is to be expected where both strains are involved. This theoretical expectation is approached closely in all cases except in pedigrees No. 5471, 5472, and 5474, in which cases the deviations from expectation are considerably more than three times the probable error. In the first two of these exceptional cases the numbers are perhaps too small to afford wholly trustworthy indications. In the case of pedigree No. 5474, however, with a total of 210 plants, there can be no doubt that the observed numbers do not fit a 9:7 ratio, as the deviation from such a ratio is over six times the probable error. The observed ratio of 151 : 59 deviated from a 3 : 1 ratio by less than twice the probable error. While no direct test of the matter has been made it would seem possible that some individuals of Wardwell's Kidney Wax, which was the susceptible parent used in this case, might be resistant to either the α or the β strain of the anthracnose fungus. If this were true, crosses involving such plants should result in 3 : 1 rather than 9:7 F_2 ratios.

Another possible source of deviation lies in the fact that it is very difficult to obtain uniform conditions for infection in all parts of a large outside inoculation chamber. As it is possible to infect the resistant Wells' Red Kidney under the most favorable conditions, it would seem reasonable to expect that in certain sections of the inoculation chamber conditions would be favorable enough to infect some plants that would otherwise be classed as resistant. On the other hand, certain sections might present conditions unfavorable for infec-

tion and plants in such sections would be classed as resistant even tho they belonged to the susceptible class. That the deviations in the thr[illegible] pedigrees under disc[illegible] by [illegible] fact that in the [illegible] many susceptible plants while in the third pedigree there are too few susceptible plants. [illegible] pedigrees al[illegible] discussed, the ratios listed in Table 2 only deviate from a 9:7 ratio by considerably less than three times the probable error. This is true in the cases where one parent is resistant and the other parent susceptible to both the α and the β strains of the anthracnose fungus and also in the cases of pedigrees No. 5483 and 5484 where one parent is resistant to only the α and the other parent resistant to only the β strain of this fungus. Grouping all of the pedigrees together the totals again approach closely to a 9:7 ratio with resistance dominant.

As a further check on the resistance of the families recorded as homozygous resistant in the summary of previous work, fourth generation plants from two of these families were crossed with the homozygous resistant parent Wells' Red Kidney. The progenies of these crosses both in the first and second generation showed as marked resistance as either parent, thus lending further proof to the first assuption that the families from which they came were homozygous for resistance.

INHERITANCE OF RESISTANCE TO THE BEAN MOSAIC ORGANISM.

Bean mosaic is a disease that has come into prominence only in late years. As yet its cause remains in the same category as that of the mosaics of other plants, namely, not proved. For a description of this disease as it occurs on the bean, the reader should consult Reddick and Stewart (8).

Material and Methods.—In the published inoculation results with bean mosaic one variety of pea bean stands out distinctly as being resistant to this disease (9, 10). This variety is the Robust bean obtained originally from the Michigan Agricultural Experiment Station and grown for a number of years by the Plant Breeding Department of Cornell University under the accession number 1986. This bean, because of its high degree of resistance and its good yielding qualities, was chosen as the resistant parent for hybridization work. The susceptible parent used almost exclusively was the Flat Marrow, which is highly resistant to root-rot but very susceptible to mosaic.

A large number of reciprocal crosses between these two varieties of beans were made in the Plant Breeding greenhouse during the

greenhouse conditions. A few families might easily have escaped infection in this instance as these F_3 plants were not grown at the Perry Laboratory grounds where insects were plentiful but in the center of a large bean field where insects of all kinds were scarce. The percentage of mosaic plants in the inoculating rows was also much lower in this field than on the laboratory grounds.

The resistant parent of the second generation plants listed in Table 5 was either the Robust Pea bean or the ordinary White Marrow reported by Reddick and Stewart (9, 10) as showing at least partial resistance to mosaic. The susceptible parent in most cases was the Flat Marrow, which shows extreme susceptibility to this disease. The great majority of the crosses were between the Robust and Flat Marrow types, the significance of which fact will be discussed later.

The totals of the resistant and susceptible plants listed in Tables 4 and 5 approach very closely to a 9:7 ratio, with susceptibility dominant. A wide deviation from such a ratio will be noticed in individual cases thruout the tables, more especially where the smaller numbers are concerned. Such a deviation in individual cases might be expected, due to the small numbers in some of the families and to the fact that it is very difficult to obtain a uniform inoculation in all parts of a field. The totals of all of the plants involved rather than the totals of any particular family should, therefore, offer a more accurate interpretation of the results obtained. This is especially so where the total numbers reach the proportion of those reported in Table 5.

In view of the ratio reported, we must assume that two factors are concerned in producing susceptibility or resistance to this disease. The presence of both of these factors in the dominant condition goes to make susceptibility. The presence, on the other hand, of one or both of their recessive allelomorphs in the homozygous condition tends to produce a plant that is resistant to the disease in question.

Plants homozygous for both dominant factors might be expected to show a greater degree of susceptibility than plants heterozygous for one or both of these factors. Similarly, plants heterozygous for only one of the dominant factors might be expected to show a greater degree of susceptibility than plants heterozygous for both of these factors. If these assumptions are correct, a gradation in resistance would be expected. Plants homozygous for the recessive allelomorphs would be expected to show as great resistance as the resistant parent and greater resistance than plants homozygous for one recessive allelomorph or plants heterozygous for one recessive allelomorph and

TABLE 5.—*Inoculation results of F_2 plants grown at Perry, N. Y.*

Pedigree No.[a]	Plants showing—		Pedigree No.[a]	Plants showing—	
	Mosaic.	No mosaic.		Mosaic.	No mosaic.
4461*	38	33	4533	7	6
4462*	32	31	4534	51	47
4463	2	0	4535	67	39
4464	1	1	4537	23	15
4466	1	0	4538	17	11
4470*	2	3	4539	50	41
4471*	8	11	4540	23	20
4472*	13	10	4541	36	27
4478*	12	15	4542	38	32
4479*	5	6	4543	20	13
4480*	12	10	4544	22	17
4481*	12	20	4545	16	13
4482*	10	15	4546	17	12
4483*	61	50	4547	61	49
4484*	34	23	4548	6	3
4485*	28	16	4549	41	20
4486*	27	20	4550	38	30
4487*	4	1	4551	74	62
4488*	26	20	4552	46	34
4489*	67	54	4553	35	30
4490*	21	17	4564	41	34
4491*	14	6	4569	12	9
4500	3	2	4570	15	21
4503	45	38	4571	20	14
4504	30	34	4572	23	17
4505	57	40	4573	22	16
4506	30	29	4574	14	10
4507	25	18	4575	22	20
4508	9	6	4578	37	30
4509	28	25	4579	60	39
4510	28	20	4581	28	20
4511	5	3	4582	50	38
4512	28	18	4586	38	32
4513	28	22	4587	38	30
4514	58	42	4593*	36	26
4515	25	17	4594*	30	18
4516	4	2	4595*	23	18
4517	48	40	4598	15	16
4519	2	1	4599	25	24
4520	2	2	4600	40	32
4521	20	11	4601	29	21
4522	18	11	4602†	34	24
4523	16	11	4604†	8	3
4524	30	18	4608†	19	12
4525	4	2	4611†	30	21
4526	33	24	4613	78	51
4527	8	9	4614†	43	30
4528	24	16	4615†	45	38
4529	47	39	4616†	63	38
4530	32	27	4617†	38	26
4531	70	63	4634	64	43
4532	24	18	4635	43	28
Observed numbers				2,982	2,290
Expected numbers (on 9 : 7 ratio)				2,965.5	2,306.5
Difference				16.5 ± 24.3	

Total number of plants tested	5,272
Number of plants severely infected with mosaic	335
Expectancy on a 9:7 hypothesis	330
Difference	5 ± 11.8

[a] The parentage of the hybrids listed in Table 5 is as follows: Numbers unmarked, Flat Marrow × Robust; Numbers marked *, Flat Marrow × Marrow; Numbers marked †, Wells' Red Kidney × Robust.

homozygous for the other. Thus, we see that almost a complete gradation would be expected from plants completely resistant to plants wholly susceptible. Such a gradation of forms actually occurs and is one of the difficulties in the way of obtaining accurate counts on resistant or susceptible plants, as the intermediate forms showing either partial resistance or partial susceptibility are difficult to distinguish from each other.

One of the methods of checking the two-factor hypothesis assumed in this case was to make accurate counts on the number of plants severely infected with mosaic. One sixteenth of the total number of plants would be the expectancy and this proportion is approximated very closely in all of the observed results. Furthermore, so far as tested, F_2 plants which were severely infected in all cases produced severely infected F_3 progenies.

With a two-factor hypothesis such as has been advanced to account for resistance or susceptibility to mosaic, we might expect to find some commercial types of beans which would belong to some of the classes intermediate between these two conditions.

Inoculation experiments (9, 10) have shown that varieties of beans differ considerably in the extent to which they become infected. In further inoculation work with hybrids of different parentage from those recorded in the present paper a different ratio might, therefore, be expected. For example, if a plant homozygous for only one of the recessive allelomorphs was crossed with the Robust type, assumed to be homozygous for both of these factors, a simple 3:1 ratio would be expected. The fact that the great majority of the crosses reported at this time were between the same two parents obviates the possibility of such ratios confusing the results when all classes of crosses are grouped together.

INHERITANCE OF RESISTANCE TO THE BEAN ROOT-ROT FUNGUS.

The root rot referred to in this article is the dry root rot caused by *Fusarium martii phaseoli* Burk. It has become widespread enough to be of considerable economic importance in the bean-growing sections of New York. This disease has recently been studied in detail by Burkholder and a full account of its life history and appearance on the bean plant may be obtained by consulting his paper (5).

Material and Methods.—In fields of White Marrow beans there often can be observed, especially toward the end of the growing season, a few plants of a more vigorous growth and darker green color than the typical marrow plants. This is the Flat Marrow bean described by Burkholder as being resistant to the dry root rot. Unfor-

tunately, it matures too late for commercial purposes but on account of its root-rot resistant qualities it was chosen as the starting point for the breeding of beans resistant to the root-rot fungus. The susceptible parent used in the greater number of the crosses was the mosaic resistant Robust Pea bean which matures considerably earlier than the Flat Marrow.

The crossing, as in the previously reported cases, was done almost exclusively in the Plant Breeding greenhouse at Cornell University. The first generation of all the crosses was also grown under the bean screen in the Plant Breeding garden at the University. The second and subsequent generations were grown on the grounds at the Bean Laboratory, Perry, N. Y. The soil on the laboratory grounds, besides being plentifully supplied in the beginning with the causal organism of the dry root rot, is reinoculated each year at planting time. The method followed is to make a spore suspension of the causal organism in water and dip the beans in this before planting. The seed while still wet is planted in damp soil. By this method the field is evenly inoculated.

Genetic Behavior in F_1.—No artificial inoculations of F_1 plants were made because of the large decrease in yield of plants badly affected with root rot. There was, however, a plentiful supply of the bean root rot organism present in several parts of the ground occupied by the F_1 plants. On these sections the roots of the hybrids became infected, thus indicating susceptibility to this disease to be at least partially dominant over resistance.

Results in F_2 and F_3.—In presenting the following F_2 and F_3 data on the inheritance of susceptibility to root rot it must be borne in mind that in studies of this kind a certain arbitrary standard must be set up to constitute a dividing line between resistance and susceptibility. The results obtained and their interpretation will depend largely on where such a dividing line is placed. For the plants under discussion in this paper, the dividing line chosen was, as far as could be determined, midway between the condition of the roots of the plants showing greatest infection during any particular season and the normal condition of healthy roots.

The proof or disproof of any hypothesis advanced to account for the inheritance of susceptibility to root rot requires a considerable amount of careful checking in later generations. All that is offered, however, in the following pages is a statement of the results obtained according to the classification used, with a tentative factorial explanation of such results as were recorded for the few generations grown.

The plants listed in Table 6 were all F_2 segregates of crosses between strains of beans resistant to root rot and strains which showed susceptibility to this disease in previous inoculation experiments. The resistant parent used almost exclusively was the Flat Marrow, the only exception to this being in a few cases where a pea bean selection which had shown considerable resistance was used in place of the Flat Marrow.

TABLE 6.—*F_2 (1918) inoculation results on bean hybrids to determine resistance to dry root rot.*

Pedigree No.	Parentage of hybrids.	Condition of the roots. Medium to severe infection.	Condition of the roots. Medium to no infection.
1592	Flat Marrow × Robust	4	3
1591	Flat Marrow × Manchurian Pea	3	3
1590	Do.	3	4
1585	Flat Marrow × Manchurian Cranberry	5	4
1584	Flat Marrow × Marrow	8	6
1583	Flat Marrow × B 39	12	10
1581	Flat Marrow × B 20	9	6
1579	Pea (Dye) × B 126	2	1
1576	Marrow × Flat Marrow	6	5
1565	Flat Marrow × Marrow	8	5
1564	Flat Marrow × Robust	12	9
1562	Do.	13	12
1561	Do.	19	11
1560	Wells' Red Kidney × Flat Marrow	9	7
1559	Flat Marrow × Robust	8	5
1558	Robust × Flat Marrow	5	5
1557	Do.	6	3
1556	Do.	16	7
1555	Robust × Pea (Dye)	8	11
1553	Do.	30	14
1552	Pea (Dye) × B 126	13	10
1551	Robust × Flat Marrow	14	18
1550	Flat Marrow × Robust	10	10
1548	Pea (Dye) × Marrow	11	7
1539	Flat Marrow × B 39	13	11
	Observed numbers	247	187
	Expected numbers (on 9 : 7 ratio)	244.1	189.9
	Difference	2.9 ± 6.2	

The numbers of plants are not large enough to be of significance in the individual families. Taken collectively, however, the results approximate, within the limits of probable error, a 9:7 ratio with susceptibility dominant. It is also true that the totals agree closely with a 27:37 ratio. With such a ratio, however, the 27 class would be the dominant class and as the smaller class is the resistant class in this case, resistance should be dominant in the first generation, an assumption which is not supported by the observed results.

Table 7 presents the F_3 inoculation results of several of the F_2 families listed in Table 6. On account of the dry season in 1918, coupled with severe root-rot infection and an early frost, a great many of the plants listed in Table 6 did not produce seed. This was particularly the case with the plants badly affected with root rot; hence Table 7 represents only F_3 families from the rather small percentage of F_2 plants that produced seed.

TABLE 7.—*Results of inoculating F_3 (1919) progenies of F_2 plants listed in Table 6.*

F_2 Pedigree No.	F_3 families from plants showing medium to severe infection in F_2.		F_3 families from plants showing medium to no infection in F_2.	
	Breeding true.	Breaking up.	Breeding true	Breaking up.
1539	2	4	4	1
1550	1	7	10	0
1551	0	0	18	0
1553	0	0	14	0
1555	1	6	10	1
1558	1	3	5	0
1560	0	0	1	0
1561	3	16	7	0
1562	2	7	12	0
1576	2	4	3	0
1579	1	0	1	0
1583	1	3	7	0
1584	1	5	3	0
1585	0	2	4	0
1591	0	3	3	0
1592	0	2	0	1
	15	63	102	3

The object of testing these families in the third generation was to find out which of the general classes under which these plants had been listed broke up in the next generation. If the families from F_2 plants which were grouped under medium to no infection broke up, it would indicate that the two-factor hypothesis assumed was not correct. On the other hand, if the families from F_2 plants which had been classed as medium to severe infection broke up, it would be in accord with such an hypothesis. An examination of Table 7 shows that the plants listed as medium to no infection in the F_2 produced progeny which, in almost every case, bred true to this condition. On the other hand, a large number of the progeny of the F_2 plants listed as medium to severe infection broke up in the F_3. It is true that a higher percentage of families from this class bred true than would be expected on a 9:7 hypothesis. This deviation from expected results may be explained, in part at least, by two disturbing conditions. The

TABLE 8.—*Results of root-rot inoculation on F_2 (1919) plants grown at Perry, N. Y.*

Pedigree No.[a]	Condition of the roots. Medium to severe infection.	Condition of the roots. Medium to no infection.	Pedigree No.	Condition of the roots. Medium to severe infection.	Condition of the roots. Medium to no infection.
4443*	12	7	4528	24	21
4444*	3	1	4529	53	41
4445*	2	2	4530	34	28
4446*	1	1	4531	80	68
4447*	3	2	4532	25	22
4448*	3	1	4533	8	7
4450*	3	2	4534	53	45
4451*	3	3	4535	62	60
4452*	2	2	4537	20	17
4454*	8	4	4538	16	16
4455*	4	4	4539	60	53
4456*	4	3	4540	28	19
4457†	12	5	4541	36	33
4458†	48	31	4542	38	30
4461†	42	36	4543	17	14
4462†	37	30	4544	22	18
4467‡	33	21	4545	16	12
4468‡	56	44	4546	15	15
4469‡	18	16	4547	66	54
4470†	3	2	4548	4	3
4471†	11	9	4549	36	26
4472†	10	8	4550	39	32
4473†	13	11	4551	72	60
4474*	4	3	4552	49	34
4475*	15	9	4553	38	34
4476*	37	24	4556	58	48
4477*	26	18	4557‡	38	32
4478†	17	13	4558‡	26	23
4479†	10	4	4564	44	36
4480†	17	11	4565†	63	56
4481†	15	12	4566†	24	20
4482†	16	13	4567†	33	19
4483†	67	51	4568	22	16
4484†	38	24	4569	10	10
4485	24	20	4570	21	18
4486†	30	22	4571	19	16
4487†	4	3	4572	28	21
4488†	26	21	4573	24	13
4489†	70	54	4574	13	13
4490†	23	17	4575	26	19
4491†	13	10	4578	40	35
4507	30	24	4579	59	46
4509	31	25	4581	26	22
4512	25	20	4582	48	43
4513	30	23	4583	15	12
4514	66	51	4584	14	12
4515	22	21	4585	55	46

[a] The parentage of the hybrids listed in Table 8 is as follows: Numbers unmarked, Flat Marrow × Robust; Numbers marked *, Flat Marrow × Wells' Red Kidney; Numbers marked †, Flat Marrow × Marrow; Numbers marked ‡, Flat Marrow × Medium.

Pedigree No.	Condition of the roots. Medium to severe infection.	Condition of the roots. Medium to no infection.	Pedigree No.	Condition of the roots. Medium to severe infection.	Condition of the roots. Medium to no infection.
4516........	5	2	4586	38	33
4517........	54	44	4587	41	34
4519........	2	1	4593†	32	25
4520........	2	1	4594†	32	25
4521........	18	15	4595†	25	20
4522........	17	14	4598	20	13
3423........	16	12	4599	28	24
4524........	29	23	4600	42	38
4525........	3	4	4601	30	23
4526........	29	22	4613	70	56
4527........	10	9			
Observed numbers				3,147	2,514
Expected numbers (on 9 : 7 ratio)				3,184.3	2,476.7
Difference				37.3 ± 25.4	

first is the difficulty of securing an even infection in all parts of the field. As far as possible the same rate of inoculation is maintained in all parts of the field but local soil conditions vary so much that the root-rot organism multiplies much more rapidly in some parts of the field than in others; hence the unevenness of infection. Probably a still more disturbing factor is the fact that root-rot infection is much more severe in some seasons than in others. In the summer of 1918 infection was much more severe than in the summer of 1919. This seasonal variation makes necessary a revised classification for each year. The dividing point between resistance and susceptibility must necessarily be different with each classification and this constitutes a possible source of error. The classification for resistance is more exacting when infection is less severe; hence it is quite possible that a number of the families classified in Table 7 as breeding true for susceptibility should have had some of their plants placed in the medium to no infection class, which would place them in the class which did not bred true and thus bring the results closer to the theoretical expectancy.

The data listed in Table 8 are all second generation inoculation results of crosses between the root-rot resistant Flat Marrow and varieties of beans susceptible to this disease. The dominating cross is the Flat Marrow by the Robust Pea bean. Many of the individual family ratios, as well as the totals for all of the families, approximate very closely the 9:7 ratio obtained with the earlier inoculations reported in Table 6. The large numbers of individuals listed in Table 8, taken with the closeness with which the totals of the inoculation results approach a 9:7 ratio, give added support to the assumptions, first, that

susceptibility to root rot is partially dominant to resistance to this disease and, second, that the results obtained are to be explained on a two-factor hypothesis.

As is the case with mosaic of the bean, various degrees of resistance and susceptibility to root rot have been observed in different bean varieties. Different ratios might be expected here also if parents of varying degrees of resistance and susceptibility were used, so that results similar to the ones here reported could only be expected when parents of a similar genetic constitution with respect to root rot resistance were used.

Discussion.

The inheritance of the ability of a plant to withstand the attacks of any particular disease-producing organism is a factor of prime importance in the production of disease-resistant varieties. A knowledge of the exact manner of this inheritance is also of great value, as such knowledge saves considerable time and unnecessary labor in obtaining the desired results. The investigations reported in this paper had for their objects, therefore, the twofold purpose of studying the method of inheritance of disease resistance and of obtaining at the same time varieties of beans resistant to the three diseases concerned.

From the families reported as homozygous resistant to anthracnose in the summary of previous work done, a number of white-seeded resistant strains have been isolated, some of which give promise of being desirable commercial types. One of the parents involved in this cross was also resistant to mosaic and some of the selected types are showing resistance to both mosaic and anthracnose. The majority of the crosses made in connection with the studies of the inheritance of susceptibility to both root rot and mosaic were reciprocal crosses between the root rot resistant Flat Marrow and the mosaic resistant Robust Pea bean. Both of these strains of beans are also resistant to the β strain of the anthracnose fungus which is the strain most commonly found in the bean-growing sections of the State. A few hundred F_2 plants have been selected from this cross which do not show either root rot or mosaic and all of which should be resistant to the β strain of the anthracnose fungus. Of course, further testing will have to be done to check the resistance of these selected strains to the root rot and mosaic organisms, but the chances are good of some of them continuing to show resistance to these two diseases. Only high yielding plants which had matured all of their pods were selected so that any of these selected strains should make desirable commercial types even apart from their evident disease resistance.

Some F_2 plants were also selected from reciprocal crosses between the Flat Marrow and the ordinary White Marrow. As mentioned before, the Flat Marrow is resistant to root rot and to the β strain of the anthracnose fungus, while the White Marrow is resistant to the α strain of the anthracnose fungus and at least tolerant to mosaic (9, 10). From this combination of parents there is a chance of securing progeny resistant to all three diseases. The magnitude of this chance naturally depends on the number of factors involved in resistance to the different diseases in question. The F_2 plants selected from this cross did not show either mosaic or root rot and, as 9 out of every 16 of these plants should possess either homozygous or heterozygous resistance to the anthracnose fungus, the chances are good of obtaining the desired results.

Summary.

Investigations of the inheritance of resistance to the bean anthracnose fungus indicate a single factor difference between resistance and susceptibility where only the α strain of the fungus is concerned in the cross. Where both the α and β strains are concerned a two-factor difference is indicated and a 9:7 ratio in F_2 is obtained. In both instances resistance is dominant over susceptibility.

F_1 and F_2 results of crosses involving the inheritance of susceptibility to the bean mosaic organism indicates a partial dominance of susceptibility over resistance to this disease. A two-factor hypothesis is advanced to account for the inheritance of resistance and susceptibility. Such an hypothesis is borne out by the totals of the observed F_2 ratios between resistant and susceptible plants and by the fact that approximately one sixteenth of these F_2 plants were severely infected with mosaic and bred true for this character in the F_3.

Inoculation results of F_2 hybrids from crosses involving the inheritance of susceptibility to root rot indicate susceptibility to this disease to be dominant over resistance. That this was the case had been indicated by the fact that a few F_1 plants, which had been grown on infested ground, showed good infection.

A tentative two-factor hypothesis to account for the inheritance of susceptibility to root rot, with a 9:7 ratio in the F_2 between susceptible and resistant plants, is advanved to explain the results obtained. The fact that the susceptible plants were in the majority in the F_2 and that a large number of the F_3 families from these plants did not breed true while the F_3 families from resistant F_2 plants in almost all cases bred true, is in accord with the hypothesis advanced.

The necessity of establishing an arbitrary dividing line between

resistant and susceptible form ... adds considerable difficulty to the proving of an... inheritance of susceptibility to bean ro...

A number of promising strains of beans have been isolated which show resistance to anthrac... A few hundred heavily podded F_2 types have been selected which show resistance to both root rot and mosaic and which should also be resistant to the β strain of the anthracnose fungus. Further testing should isolate some very desirable resistant commercial types from these selections.

Literature Cited.

1. Barrus, M. F. An anthracnose resistant Rid Kidney bean. *In* Phytopath., 5: 303–311, figs. 1–4. 1915.
2. ——. Varietal susceptibility of beans to strains of *Colletotrichum lindemuthianum* (Sacc. and Magn.) Bri. and Cav. *In* Phytopath., 8: 589–614. 1918.
3. Biffen, R. H. Mendel's law of inheritance and wheat breeding. *In* Jour. Agr. Sci., 1: 40–44. 1905.
4. Burkholder, W. H. The production of an anthracnose resistant White Marrow bean. *In* Phytopath., 8: 353–359. 1918.
5. ——. The dry root-rot of the bean. Cornell Univ. Agr. Expt. Sta. Memoir 26, p. 1003–1033. 1919.
6. McRostie, G. P. Inheritance of anthracnose resistance as indicated by a cross between a resistant and a susceptible bean. *In* Phytopath., 9: 141–148. 1919.
7. Nilsson-Ehle, H. Resistenz gegen Gelbrost beim Weisen. *In* Kreusungsuntersuchungen an Hafer und Weisen. Lund's Universitets Arsskrift N. F, Afd. 2, 7: 57–82. 1911.
8. Reddick, D., and Stewart, V. B. Bean mosaic. *Abs. in* Phytopath., 7: 61. 1917.
9. ——. Varieties of beans susceptible to mosaic. *In* Phytopath., 8: 530–534. 1918.
10. ——. Additional varieties of beans susceptible to mosaic. *In* Phytopath., 9: 149–152. 1919.
11. Stuckey, H. P. Transmission of resistance and susceptibility to blossom-end rot in tomatoes. Ga. Agr. Expt. Sta. Bul. 121, p. 83–91. 1916.
12. Tisdale, W. H. Flax wilt. A study of the nature and inheritance of wilt resistance. *In* Jour. Agr. Research, 11: 573–606. 1917.
13. Vavilov, N. I. Breeding for resistance to rust and mildew in wheat. *In* Jour. Genetics, 4: 49–65. 1914.

HYDROCYANIC ACID IN SUDAN [illegible] ON CATTLE.[1]

C. O. SWANSON.[2]

This paper is a preliminary report of work still in progress. It is planned to extend the investigation and to obtain additional data to confirm some of the results obtained. A number of observations reported in this paper are new only as to Sudan grass, several investigators having made similar observations in connection with other plants. Citations to literature will be deferred to a future paper, as will discussion of theories.

Sudan grass is one of the important forage crops in the Southwest. Occasional cases of poisoning have been reported. In August, 1919, a farmer near Abilene, Kans., lost several head of cattle, death apparently being caused by poisoning from Sudan grass. A sample of the grass sent to the laboratory was tested for hydrocyanic acid, but none was found. The grass was wilted and partially dry when obtained. Later experiments demonstrated that tests made on grass in this condition may be worthless.

In the fall of 1919, the Dairy Department of the Kansas State Agricultural College used a plot of 5.4 acres of Sudan grass for pasturing six Holstein cows. The cows were in good condition and gave the usual amount of milk. Because of reported cases of poisoning from Sudan grass, it was thought worth while to test this grass for hydrocyanic acid.

All samples were hand picked, taken from various parts of this pasture in such size as the cows would gather. The samples were taken at once to the laboratory and passed thru a small feed cutter and a 5-liter flask filled half full. To this was added enough water to cover the cut grass and acidified with sulfuric acid. About 400 c.c. were distilled into a dilute solution of potassium hydroxid. To this was added a small amount of ferrous sulfate and hydrochloric acid to acid reaction and the solution warmed gently. The amount of hydrocyanic acid present was judged by the intensity of color. A deep blue indicated a large amount and a faint blue, a trace. This

[1] Contribution from the Department of Chemistry, Kansas Agricultural Experiment Station, Manhattan, Kans. Published by courtesy of the American Chemical Society. Paper read at the St. Louis, Mo., meeting, April, 1920. Received for publication September 11, 1920.

[2] Associate chemist, Kansas Agricultural Experiment Station.

was the usual method of procedure when it was desired simply to learn if hydrocyanic acid was present. Modifications were introduced, as will appear, in order to show the effect of certain factors. No quantitative tests were made.

The first sample was collected September 12. The test, made at once on the green grass, showed the presence of large amounts of hydrocyanic acid. A portion of this sample was allowed to dry and this, when tested, gave only a faint trace. This suggested that the condition of the grass might have had something to do with the results of the tests. Accordingly a number of experiments were made in order to determine the optimum conditions for making the test. It was found in all cases that the maximum amount of hydrocyanic acid, if present, was obtained when the test was made on the green material immediately after cutting. A sample picked in the afternoon would show a large amount of hydrocyanic acid in the portion tested at once, while in the portion kept till the next day, only a trace or none at all would be found. Such experiments with several minor modifications showed that if the tests were to have any value they must be made on the grass immediately after cutting.

After these experiments had been performed, new samples were obtained from the field near Abilene where the poisoning had occurred. While they had to be brought 40 miles, care was taken to prevent wilting. Large amounts were found, but apparently not larger than in several samples from the pasture on the Agronomy farm.

The rate of drying is important. Samples were divided into several portions. One was dried slowly in the shade, one in the sun, one in an oven having a current of air heated to 70°, and on one the test was made immediately after cutting. The portion tested at once gave large amounts, that dried in the oven somewhat less, that dried in the sun still less, and that dried slowly in the shade none or only a trace.

The addition of sulfuric acid is not necessary for the test if it is made at once on the green material. Samples were divided into three portions. Sulfuric acid was added to one, hot water to another, while the third was digested in water at room temperature for several hours. On distillation, the last one gave larger amounts than the other two.

One sample was divided into two portions. One portion was treated with chloroform by placing in a closed can for about an hour and then dried rapidly. The other portion was placed at once in the

air oven and dried. The portion treated with chloroform gave the stronger test.

These experiments make it appear that hydrocyanic acid is liberated by enzymes. If these are destroyed by the addition of hot water, sulfuric acid, or treatment with dry heat, not as much hydrocyanic acid is obtained as when the tests are made at once on the green grass simply by digesting in water at room temperature and then distilling.

Slow drying was not the only way in which the hydrocyanic acid would disappear. Samples of Sudan grass known to give strong tests for hydrocyanic acid were placed, without first passing through the feed cutter, in flasks and kept moist and green for several days. Tests by the use of sulfuric acid and by digesting in water failed to show any hydrocyanic acid present. This experiment was varied by passing air continuously thru the flask, but the result was the same. Green samples were placed in an open pan and kept moist for about a day. This treatment apparently had no effect on the amount of hydrocyanic acid obtained. It was not determined how long it would take under such conditions for the hydrocyanic acid to disappear.

Converting Sudan grass into silage did not cause hydrocyanic acid to disappear. Samples were cut fine, packed tightly into milk bottles, and sealed. When two weeks old the bottles were opened and the material was excellent silage. One portion of this silage was digested in water and then distilled. Large amounts of hydrocyanic acid were found. The acid did not disappear rapidly from this silage. Another portion was placed loosely in an open Mason jar and allowed to remain over night. On digesting in water and distilling, large amounts were found.

While these tests were being made, the cows remained on the grass and apparently in good health. As these cows had been on this pasture form July to October, it was thought that the effect might be different if cows not used to Sudan grass were allowed to eat it. Accordingly, on October 3, two other cows which had not eaten any Sudan grass were placed in this pasture. These cows seemed to suffer no ill effects. The grass was tested on this date and apparently contained as much hydrocyanic acid as at any time.

Freezing Sudan grass did not diminish the amount of hydrocyanic acid obtained if the test was made before the grass thawed and wilted. A sample was frozen by placing over night in an ice machine. The temperature was about 20° F. One portion was cut at once, digested in water, then distilled. This gave a much larger amount than was

obtained on another portion which was allowed to wilt before it was tested. Another portion was allowed to dry first and from this no hydrocyanic acid was obtained.

The first killing frost of the season occurred October 11. The cows were taken from the pasture the evening before, so no report can be made as to what the effect might have been if they had been allowed to remain another day. It was known, however, that some farmers in the neighborhood were pasturing cattle on Sudan grass at this particular time and continued to do so beyond October 11. As far as is known, no ill effects were observed. While no tests had been made on any of these grasses yet the strong probability is that hydrocyanic acid was present.

A sample of Sudan grass was obtained on the morning of October 11 while the frost was still on the grass. The results on this sample were the same as from that frozen artificially. In the afternoon of the same day another sample was obtained. The grass was now wilted and black. This sample gave a very small amount of hydrocyanic acid. On the next day another sample was gathered, and not a trace of hydrocyanic acid could be found.

Summary.

1. Hydrocyanic acid was found in large amounts in Sudan grass used for pasture and no harm resulted to the cattle.

2. Liberation of hydrocyanic acid from Sudan grass is apparently associated with enzyme action. Digesting in water at room temperature for several hours and then distilling gave larger amounts of hydrocyanic acid than if sulfuric acid was added at once. Hot water and dry heat diminished the amount of hydrocyanic acid obtained. Slow drying caused the hydrocyanic acid to disappear. Tests made on wilted samples or those several days old may be worthless.

3. Making Sudan grass into silage did not diminish the amount of hydrocyanic acid obtained.

4. Tests made immediately on frosted Sudan grass gave very large amounts of hydrocyanic acid, but it disappeared rapidly as soon as the plant began to wilt; when dry the hydrocyanic acid had disappeared.

5. While Sudan grass giving a strong test for hydrocyanic acid was not harmful to cattle, under other conditions it was harmful. Immunity was not due to habituation.

SIX YEARS' EXPERIENCE IN IMPROVING A LIGHT, UNPRODUCTIVE SOIL.[1]

BURT L. HARTWELL and S. C. DAMON.[2]

The land upon which the experiment was conducted adjoins the college property on the north and was leased from E. Sweet. The soil is classified as Warwick sandy loam, of which there is considerable easily tilled area in the State. The field had not been tilled, cropped, nor manured for many years. The turf had become very thin, and moss had taken the place of grass to such an extent that a season's growth did not yield a quarter ton of hay. The subsoil was a coarse gravel, and leaching could take place readily. Aside from manurial requirements, the fundamental needs appeared to be for lime and for organic matter to conserve moisture. Six apparently uniform, level plats of a quarter acre each were used in the experiment, which was begun in 1913.

The plan was to prepare in different ways for a uniform planting of potatoes in 1917, with the hope that the effect of the various procedures might be shown on this cash crop. Winter wheat was sown uniformly following the potatoes and harvested in 1918, after which the station gave up the land. The general cropping system followed on the different plats will now be described briefly.

On plat 1, the plan was to grow on the acid soil such crops as might develop there, with the main object of increasing the organic matter. They comprised lupine for green manuring, followed by rye as a cover crop, in 1913; soybeans for green manuring in 1914, followed by redtop in the fall and alsike clover in the spring; this, on account of failure, was replaced by corn in 1915. At the last cultivation of the corn, grass and clovers were again sown, to be harvested for hay in 1916.

On plat 2, lime was used more liberally and corn planted in 1913, in which grasses were seeded, supplemented by a seeding with clover the next spring. Hay was harvested each year until the turf was turned under in the autumn of 1916 in preparation for the potatoes in 1917.

[1] Contribution 269 from the Agricultural Experiment Station of the Rhode Island State College, Kingston, R. I. Received for publication April 25, 1920.

[2] The senior author is director and agronomist and the junior author is assistant in field experiments, Rhode Island Agricultural Experiment Station.

Plat 3 was left in an acid condition and differed from plat 1 principally by having soybeans instead of lupine in 1913, and by the fact that rye was used in the fall of 1914. The grass seeding persisted in this case so that corn was not planted as on plat 1.

Plat 4 was plowed in 1913 the same as the other plats, but was then seeded to redtop without ever being fertilized or limed. What little grass grew each year was cut and left to decay so that the plat might remain practically in its original condition till prepared for the potatoes of 1917.

Plats 5 and 6 were both planted to corn in 1913, in which were sown alfalfa on plat 5, and sweet clover and winter vetch on plat 6. The legumes were plowed in for green manures in 1914 before seeding to grasses and clovers, for producing hay in 1915 and 1916.

The influence of the various treatments on the potatoes grown in 1917 on the different plats was so slight that it may be considered as fairly within the limits of experimental error. The total yields of potatoes of the Green Mountain type in bushels per acre were as follows: plat 1, 276; plat 2, 274; plat 3, 289; plat 4, 272; plat 5, 290; plat 6, 274. The satisfactory rainfall, the uniform application per acre of 60 pounds of nitrogen, 130 pounds of phosphoric oxid, and 50 pounds of potassium oxid, together with the fact that potatoes are not sensitive to differences in soil acidity, had left insufficient opportunity for the variations in previous treatments to exert a pronounced effect on potatoes. Therefore, the description of the details of the previous lime and fertilizer treatments may be considered first in connection with the winter wheat in 1918. This crop was considerably influenced, as may be seen by the following yields per acre:

Plat.	Grain, including many unthrashed heads, lbs.	Straw, lbs.
1	404	1,232
2	832	2,328
3	548	2,128
4	456	1,664
5	1,052	2,748
6	1,128	3,152

No advantage, but possibly some disadvantage, resulted to the wheat coincident with the attempt on plat 1 to introduce organic matter by green manure crops capable of growing on the soil in its sour condition. Comparison should be made with plat 4, which in the preliminary period served as a check plat. A portion of plat 1 which had received a small amount of lime produced a somewhat better yield of wheat than the remainder of the plat which remained unlimed.

Plat 2, as distinguished from plat 1, had received sufficient lime for wheat, and the beneficial effect of the liming is shown plainly in the yield. From supplementary tests it appears improbable that the increased yield was due to a somewhat larger amount of fertilizer added to plat 2 than to plat 1 or 3. The small increase in yield on plat 3 may be attributable to the presence of the lime in the Thomas slag phosphate which was used in 1913 and 1914 to supply 80 pounds of phosphoric oxid, whereas acid phosphate was used on plat 1.

Plats 5 and 6, which produced much the largest amount of wheat, were fertilized and limed alike during the entire experiment. Each received 3,000 pounds of hydrated lime per acre in 1913 and a ton of ground limestone in 1914; whereas plat 2 received altogether only 2,250 pounds of limestone per acre. As plats 5 and 6 received no more fertilizer than plat 2, it is probable that the extra lime was the cause of the larger yields.

The only difference between plats 5 and 6 was that in 1913 alfalfa was seeded in the corn on the former, and a mixture of sweet clover and vetch on the latter. On August 3, 1914, when the crops were plowed under, the alfalfa was scattering and about a foot tall. The sweet clover was about 3 feet tall, and the total weight of green material on this plat, no vetch having wintered, was twice that on the alfalfa plat, or about 6 tons per acre.

Both plats were seeded down to grasses and clovers in the autumn of 1914, and the following year, after being topdressed at the rate of 30 pounds of nitrogen in nitrate of soda, 50 pounds of phosphoric oxid in acid phosphate, and 40 pounds of potassium oxid in muriate of potash, yielded hay as follows: plat 5, 3.1 tons per acre; plat 6, 2.6 tons per acre.

In 1916, hay was harvested not only from these plats, but from plats 1, 2, and 3. The yields in tons of hay per acre are assembled for comparison: Plat 1, 3.9; plat 2, 3.0; plat 3, 3.0; plat 4 (check), very little; plat 5, 3.4; plat 6, 3.6.

Each plat had been topdressed that year at the rate of 300 pounds of common salt and 386 pounds of acid phosphate. Plats 1 and 3 received 30 pounds of nitrogen, plat 2, 40 pounds, and plats 5 and 6, 50 pounds each, all in nitrate of soda. It was estimated that on the very acid plats 1 and 3 about nine tenths of the grass was redtop, the remainder being mostly timothy; whereas on plat 2, which had received 2,250 pounds of limestone in 1913, the reverse was true.[8]

[8] This plat produced per acre in 1913 22 bushels hard corn, 21 bushels soft corn, and 1.19 tons stover; in 1914 1.88 tons hay; and in 1915 2.19 tons hay: with the total addition for the three years of 100 pounds nitrogen, 150 pounds of prosphoric oxid, and 120 pounds potassium oxid.

It was ascertained from samples that, in 1913, 4,150 pounds per acre of green lupine coutaining 18.7 pounds of nitrogen were plowed in on plat 1, and 8,973 pounds of green soybeans containing 56.5 pounds of nitrogen were turned under on plat 2.

Altho it had been decided to depend upon the potato crop of 1917 to demonstrate some of the effects of the different treatments of the plats, it was realized that the tolerance of this crop for soil acidity unfitted it to show the effect of liming. It was thought probable, however, that soil so light, and in its original condition so devoid of humus, would some time during the summer be sufficiently lacking in moisture so that the moisture-conserving effect of the green manures added to certain plats would be demonstrated by the potato yields. Consequently, the potatoes were fertilized liberally on all plats in order that the organic matter might be the influencing factor if the season was dry.

As so often happens, however, under the uncontrollable conditions in the field, the very circumstances in which the demonstration might be expected to prove successful did not exist. The season was a wet one, and the potatoes yielded as much on the control plat as on any which had received considerable increment of humus from the green manures. Not only was the temperature of April and May below the normal for those months, but the rainfall was liberal during the time of most rapid growth, as shown by the following: April, 3.01 in.; May, 5.48 in.; June, 5.25 in.; July 1.71 in.; August, 2.85 in.

In our generally humid climate, it might take many years to demonstrate, under field conditions, the accepted moisture-conserving value of humus, and it is not a surprise that this was not done during the limited time of this experiment.

One would scarcely have predicted, however, that even with the liberal rainfall and fertilizer, the control plat would produce 272 bushels of potatoes. In case of this plat, the light, unproductive pasture soil was simply plowed and seeded to redtop in 1913, after which nothing was added nor removed until it was plowed again in the fall of 1916 and fertilized in the spring of 1917 in preparation for potatoes.

Winter wheat, which was grown after the potatoes, is sufficiently sensitive to acidity so that the liming on certain plats appeared to be at least the principal factor influencing its growth. The rainfall in the spring of 1918 during the months when it would be most useful to the wheat was as follows: March, 2.72 in.; April, 5.60 in.; May, 2.29 in.; June, 4.71 in. With such a liberal rainfall, it could scarcely

be expected that a possible increase in moisture conservation by additional humus would have any effect on the crop.

The very pronounced influence of the liming, wheneve a crop was grown which is sensitive to soil acidity, shows that the first consideration should be given to this process in connection with attempts to increase crop production on such soils. Of the fertilizer elements, phosphorus would probably be used most economically, while legumes should prove beneficial in the long run, not only for collecting nitrogen but for increasing the humus.

A PRELIMINARY NOTE ON THE INHERITANCE OF RUST RESISTANCE IN OATS.[1]

R. J. GARBER.[2]

Breeding for rust resistance in wheat has been carried on rather extensively, but in oats little has been done. Parker has made a varietal survey[3] of oats with respect to rust reaction and also reported[4] on the behavior in the F_2 of a cross between parents differing in their reaction toward crown rust (*Puccinia lolii avenae*). In this cross susceptibility to crown rust was inherited as a dominant character.

During the summer of 1918, crosses[5] were made between a selection of White Russian oats (*Avena sativa orientalis*) resistant to stem rust (*Puccinia graminis avenae*) and a selection from each of the two highest yielding varieties grown at University Farm. These varieties, Minota and Victory (both *Avena sativa*), are very susceptible to stem rust.

The F_1 plants were grown in the greenhouse the winter after the crosses were made and a limited number matured soon enough to permit growing a small F_2 generation the following summer. Ma-

[1] Published with the approval of the Director as Paper No. 215, of the Journal Series of the Minnesota Agricultural Experiment Station, University Farm, St. Paul, Minn. Received for publication August 23, 1920.

[2] Formerly assistant in plant breeding, Minnesota Agricultural Experiment Station.

[3] Parker, J. H. Greenhouse experiments on the rust resistance of oat varieties. U. S. Dept. Agr. Bul. 629, 16 p. 1918.

[4] Parker, J. H. A preliminary study of the inheritance of rust resistance in oats. *In* Jour. Amer. Soc. Agon., 12: 23-38. 1920.

[5] These crosses were suggested and the parental material furnished by H. K. Hayes, Head of the Section of Plant Breeding, Division of Agronomy and Farm Management, University of Minnesota.

tured seed from three different F_1 plants of the cross, Minota $\times$ White Russian, and from a single F_1 plant of the cross, White Russian $\times$ Victory, were sown in the nursery in a manner to permit in-

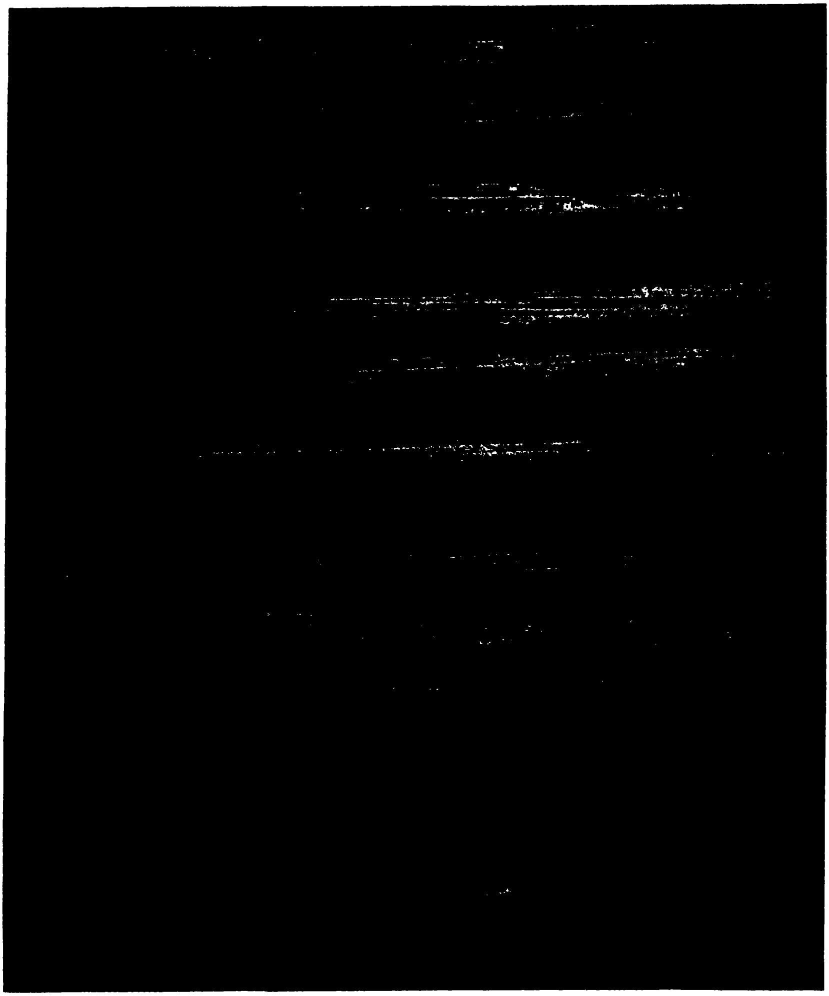


FIG. 1. Culms of susceptible and resistant oats. From top to bottom, in groups of three: Susceptible Victory parent; susceptible plant of F_2 of White Russian $\times$ Victory; resistant plant of F_2 of White Russian $\times$ Victory; resistant White Russian parent. Note normally developed uredinia on the Victory plant and on one of the F_2 plants.

dividual plant study. In all there were 142 F_2 plants of the former cross and 41 F_2 plants of the latter. The parents were sown similarly in rows beside those of the F_2 plants. The F_2 plants and their

parents were sown about two weeks after the rest of the oat nursery. The summer of 1919 proved to be favorable to the development of stem rust and a heavy natural epidemic occurred. In addition, rust spores were artificialy applied to the parents and F_2 plants. Owing to the lateness of seeding, both the progeny and parents were especially subjected to the attack of rust. Under the above conditions, the susceptible parents became heavily rusted whereas none or very few small uredinia developed on the resistant White Russian variety.

The F_2 plants showed sharp segregation and were placed in two classes, those similar to the susceptible parents and those similar to the resistant parent (see fig. 1). Eliminating three plants of somewhat doubtful classification the results obtained in F_2 were as follows:

Minota × White Russian, 104 resistant, 36 susceptible

White Russian × Victory, 31 resistant, 9 susceptible.

Here is evidence of a single hereditary factor difference with respect to the rust reaction of the host plants used as parents. Resistance apparently behaves as a dominant character in these crosses.

AGRONOMIC AFFAIRS.

THE SOCIETY IN 1921.

The American Society of Agronomy has just passed thru a hard year. With no appreciable change in total membership, there was a marked increase in printing costs, which necessitated the curtailment of the JOURNAL in recent months. The unrest following the war has seemed to make it difficult for us to hold old members and to get new ones. The annual meeting of the Society at Springfield, Mass., in October, however, was the most successful ever held, and it is believed marked a milestone in our progress. The development of the symposium idea in the programs has greatly stimulated interest in the meetings and the publication of the resulting papers should add greatly to the value of the JOURNAL. In the February issue the six papers presented at Springfield on the teaching of crops and soils will be printed, and these will be followed by the lime papers. Later, the corn improvement papers from the special program meeting held at Chicago on December 31 will appear. These with other special articles should make up a very interesting volume for 1921. The only question now is, will the Society have sufficient funds to print all the worth-while papers?

Two ways out of the financial difficulty facing the Society were

suggested at Springfield, increasing the annual dues and increasing the membership. A slight increase in the annual dues (from $2.50 to $3.00) was voted, and plans for a vigorous campaign for members were discussed. That this campaign is going forward successfully in some sections is evident from the number of new members added recently. It is hoped that this is but an earnest of what is to come, for of the 77 new names 54 are from three States, 24 from Iowa, 18 from Texas, and 12 from Kansas. With 45 States yet to hear from, there is room for abundant further growth. Which State will head the list a month from now? Texas now leads in total members, with 42; Kansas is a close second with 38.

Do agronomists hold their profession too cheaply? Why is it that the American Chemical Society, with dues of $10 a year, has several thousand members, while the American Society of Agronomy struggles along with a few hundred members at $2.50? At the last annual meeting of the chemists it was shown that the $10 dues were not sufficient to meet the needs of the Society, and the amount was raised to $15! Surely agronomists ought to take sufficient pride in their profession to support their own Society, when the cost is so small. Let's set the mark this year at 1,000 members, and then see how far we can go past it!

BOOK REVIEW.

SOIL ALKALI: ITS ORIGIN, NATURE AND TREATMENT. *By F. S. Harris. 258 p., illus. New York, John Wiley and Sons, 1920.*—To one who has even a superficial knowledge of the soil resources of the western United States, especially that part of the country lying west of the continental divide, the importance of the alkali problem is clearly apparent. When one realizes that this country contains only a minor portion of the alkali lands of the world, the importance of the problems involved in securing a satisfactory utilization of these lands is profoundly impressive. The challenge of the alkali problem has been accepted by a large number of investigators. Chemists, agronomists, botanists, engineers, economists, and other specialists have attacked it with varying degrees of ability and persistence, and with varying productiveness. None of them has solved it, but each has left his contribution, large or small, for whatever use the world can make of it. The aggregate value of these contributions is very great. In bringing together in one small volume brief summaries,

showing many of the outstanding features of the contributions made to the literature of soil alkali by no fewer than 180 investigators, Dr. Harris has rendered a distinct service.

The book should be useful, with its short chapters in which a large number of the commonly considered aspects of the subject are briefly discussed in simple language, and with its extensive bibliography.

The author makes a high estimate of the aggregate area of alkali lands, and devotes to their geographic distribution a chapter which would be improved by the use of a good map and of more definite statistics, if they were available, as they probably are not. He then discusses the origin of alkali, placing special emphasis on the geologic factors; the nature of alkali injury to plants; toxic limits, which, by the way, are very imperfectly understood; indicator vegetation; methods of making alkali determinations; equilibrium and antagonism among alkali salts; the relation to alkali to physical and biological conditions in the soil; the movement of soluble salts in the soil; methods of reclaiming alkali lands, with a separate chapter on drainage; crops for alkali lands; alkaline water for irrigation; and methods of judging alkali lands. He quotes freely from Hilgard, Cameron, Kearney, Briggs, and other investigators, and from publications by himself and his associates.

In reading the book one is impressed with the large number of essential points which need further investigation. The author alludes repeatedly to this need, and by the very frequent use of the verbs "may" and "might," indicates perhaps how keenly he feels it. The alkali question has many complexities and ramifications, and our facilities for investigating it are very inadequate. In writing a textbook on the subject, a conscientious author probably experiences frequently a conflict between his desire to be constructively informative and his anxiety to avoid making ill-founded statements.

The problems involved in the utilization of alkali lands, even more perhaps than those which are encountered in the reclamation of some of our most sandy areas, require of the student more than usual patience, persistence, ingenuity, and intelligent optimism. These problems are a persistent challenge. Their complete solution would be of immeasurable benefit. It would make available for large populations vast regions of territory admirably located and favored with the most delightful climates. It is regrettable that we do not have a sufficient number of men with the necessary training, temperament, and opportunity to attack the problem on a thoroly comprehensive scale and, if need be, on a life-long basis.—F. D. F.

MEMBERSHIP CHANGES.

It is a pleasure to report that since copy for the last issue went to press the largest number of new members ever reported in a like period has been received. Unfortunately, however, at this time the members whose dues for 1920 have not been paid and whose memberships have therefore lapsed must also be reported. This number slightly exceeds the additions, so that a slight net loss is shown. It is entirely probable, however, that some of those now listed as lapsed will arrange for their reinstatement later, so that the Society is now in a position to go forward, new members added to the list after this time being a distinct gain. The membership reported in the last issue was 556, since which time 77 new members have been added, 1 member has resigned, and 81 have been dropped for nonpayment of 1920 dues, making a net loss of 5 and a present membership of 551. In order to save space, names and addresses of new members, names of resigned and lapsed members, changes of address, and other membership changes will no longer be printed in the JOURNAL. Members are urged to report changes of address or failure to receive the JOURNAL to the Secretary or the Editor. Every effort is made to keep the mailing list complete and correct, but members must cooperate in this undertaking.

NOTES AND NEWS.

Mark A. Carleton, formerly cerealist of the Federal Department of Agriculture, is now plant pathologist for the United Fruit Company, with headquarters at Bocas del Toro, Panama.

H. R. Cates, formerly agronomist in charge of weed investigation in the Department of Agriculture, resigned August 15 to accept a position in the crop insurance department of the Hartford Fire Insurance Co., with headquarters at Atlanta, Ga.

G. C. Creelman, for many years president of the Ontario Agricultural College, has resigned to become agent-general for Ontario in London, the business of his office being largely the direction of the attention of prospective immigrants to Ontario's agricultural opportunities. He has been succeeded at Guelph by J. B. Reynolds, formerly president of the Manitoba Agricultural College.

C. O. Cromer, formerly assistant in farm crops at the Purdue University station, has resigned to engage in farming at Daleville, Ind.

E. P. Deatrick is now connected with the department of soil technology in the Cornell University college of agriculture.

Geary Eppley is now assistant in agronomy and J. R. Haag is assistant in soils at the Maryland college and station.

Thomas F. Hunt, dean of the college of agriculture of the University of California, now on a year's leave of absence in England, has been appointed delegate to represent the United States at the International Institute of Agriculture at Rome.

W. D. Hurd is now director of the Soil Improvement Committee of the National Fertilizer Association. On October 1 this committee established headquarters in Washington, D. C., with offices in the Southern Building.

Ralph E. Johnston is now extension agronomist in South Dakota.

Dr. David Kinley, professor of economics and dean of the graduate school of the University of Illinois, has been elected president of that institution.

Dr. Ernest H. Lindley, for the past three years president of the University of Idaho, is now chancellor of the University of Kansas.

Henry F. Murphy is now assistant in agronomy at the Oklahoma college and station.

J. C. Overpeck is now assistant professor of agronomy in the University of Wyoming and assistant agronomist of the station.

P. H. Ross, formerly State leader of county agents in Missouri, is now director of extension in that State, succeeding A. J. Meyer, who resigned to become executive secretary of the Missouri State Farm Bureau.

Nelson S. Smith, formerly a member of the faculty of the agricultural school at Claresholm, Alberta, is now engaged in farming at Olds, Alta.

Rupert L. Stewart, formerly agronomist of the New Mexico college and station, now has charge of the Smith-Hughes agricultural teaching in the Pomona, Cal., high school.

E. P. Taylor, formerly director of extension in Arizona, is now with the fertilizer department of the Anaconda Copper Mining Company, with headquarters at Chicago, Ill. He has been succeeded as director of extension by W. M. Cook.

C. M. Woodworth, for the past several years engaged in flax-disease studies for the Federal Department of Agriculture in cooperation with the Wisconsin station, is now engaged in plant-breeding investigations with the department of agronomy of the Illinois college and station.

H. L. Shantz returned to Washington, D. C., early in September, after more than a year of agricultural exploration in Africa for the United States Department of Agriculture, during which time he crossed Africa from the Cape to Cairo and made many side trips to little-known districts. He has now been placed in charge of the physiological and fermentation investigations of the Bureau of Plant Industry.

INTERNATIONAL CROP IMPROVEMENT ASSOCIATION.

The second annual meeting of the International Crop Improvement Association, a federation of the State and Canadian crop improvement and experimental associations, was held at the Stock Yards Inn, Chicago, on December 1, 1920, in connection with the International Grain and Hay Show. The general topic for discussion was "Seed Inspection, Certification, and Marketing." The following program was presented:

1. Canada's Method, by L. H. Newman, Secretary Canadian Seed Growers' Association, Ottawa, Ont.
2. Opinions from Indiana's Experience, by W. A. Ostrander, Indiana Corn Growers' Association, LaFayette, Ind.
3. Michigan's Inspection and Marketing System, by A. L. Bibbins, Secretary Michigan Crop Improvement Association, East Lansing, Mich.
4. Alfalfa Seed Inspection in Idaho, by B. F. Sheehan, Secretary Idaho Seed Growers' Association, Boise, Idaho.
5. Grimm Alfalfa Seed Inspection, by W. R. Porter, Secretary Grimm Alfalfa Seed Producers' Association, Fargo, N. Dak.

At the conclusion of the program, the following officers were elected for the ensuing year:

President, G. H. Cutler, University of Alberta, Edmonton, Alta.

First Vice-President, R. A. Moore, University of Wisconsin, Madison, Wis.

Second Vice-President, B. F. Sheehan, State Seed Commissioner, Boise, Idaho.

Third Vice-President, A. L. Bibbins, Mich. Agr. College, East Lansing, Mich.

Secretary-Treasurer, J. W. Nicolson, Michigan Farm Bureau, East Lansing, Mich.

JOURNAL

OF THE

American Society of Agronomy

VOL. 13. FEBRUARY, 1921. No. 2

PREREQUISITES FOR AGRONOMY SUBJECTS.[1]

L. E. CALL.

The subject assigned to me on the program is too broad in one direction properly to state the material that I wish to present this afternoon, and too narrow in another direction. With your permission I will confine my paper to a discussion of prerequisites for farm crops subjects and especially those that are required of all agricultural students in most educational institutions. On the other hand, I wish to broaden the scope of my paper to include a discussion of the place in the curriculum where the required work in farm crops should be given.

A year ago this fall at the annual meeting of this Society a few minutes were used to discuss the subject of farm crops teaching. At that time there seemed to be a great difference of opinion as to whether the required work in farm crops should be offered in the freshman, sophomore, or junior year. There was also a difference of opinion as to the desirability of requiring any training in the sciences as a prerequisite for the work in crops.

Since that time I have had an opportunity to study the curricula as given in the most recent catalogs of a number of the leading agricultural colleges and universities of this country. In all, the courses of study of twenty-five of the leading institutions offering work in agriculture were compared. Of these institutions nine give their required work in farm crops in the freshman year; two other institu-

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] Professor of Agronomy, Kansas State Agricultural College, Manhattan, Kans.

tions offer brief courses in the freshman year called "Crop Production" or "Agronomy." These courses in both cases are a part of the year's work in agriculture made up of work offered by the departments of animal husbandry, dairy husbandry, horticulture, and agronomy. In both instances these institutions give other required work in farm crops that is taught in the junior year after the student has received some training in botany. Seven institutions offer their required work in the sophomore year, six in the junior year, while three institutions, whose courses are largely elective, do not require any farm crops work of all agricultural students. All of the institutions which offer the required courses in farm crops in the sophomore or junior years require general botany as a prerequisite for crops. Some of them mention chemistry specifically as a prerequisite, and two institutions that offer the farm crops work in the junior year require soils as a prerequisite. One institution that offers farm crops in the freshman year mentions the fact that general botany must accompany or precede the work in this subject. Of the twenty-five institutions whose courses of study were investigated, sixteen recognize the value of botany as a prerequisite for farm crops, and a few others specifically mention chemistry and soils.

It appears from this study of curricula that the leading institutions requiring work in farm crops can be grouped into three classes in respect to the requirement of prerequisites for this subject. First, those that require no prerequisite and offer farm crops in the freshman year; second, those that require general botany as a prerequisite and offer the work in the sophomore or junior year; and third, those that require general botany and soils as prerequisites and offer the work in the junior year. There are probably advantages and disadvantages that can be mentioned for each of these arrangements. Perhaps no one of them will answer the requirements at every institution in the United States, but it would certainly seem that it would be possible to have a greater uniformity among our institutions than now exists in both the prerequisites required for farm crops and as to the year in the curriculum that the course is offered. Probably few other required subjects in the agricultural course have been "wiggled and wobbled" around like the courses in farm crops.

Those institutions that offer farm crops in the freshman year and require no prerequisite for the course generally admit that it would be desirable to have general botany preceding the work in crops, but in order to accomplish this it would be necessary to postpone the work in crops until the sophomore year. In so doing they lose the sup-

posed advantage of. first, using farm crops in the freshman year as a means of holding the interest of the student in agriculture or, in other words, using it as a sugar coating to the bitter dose of science that the student is required to swallow; and second, using the subject as a means of meeting the agricultural students in the freshman year and in that way interesting them in farm crops with the hope that they may later specialize in this phase of agriculture. Let us use a few moments to consider the first reason for offering farm crops in the freshman year, that is, as a means of holding the student's interest in agriculture. First, is it necessary to offer agricultural work during the freshman year in order to hold the student's interest, and second, if it is necessary to do so, is farm crops the subject that should be used for this purpose?

There is a difference of opinion among different educators as to the desirability of offering any strictly agricultural work during the freshman year. Some think that the entire year should be used to give the student the training in English and the sciences which he will need later for his work in agriculture. Most educators who have studied the question believe that while it is desirable to devote as much time as possible to the sciences during the freshman year that at least a small amount of practical or applied agricultural work should be given during this period. If we admit this to be desirable, should farm crops be the course used for the purpose? I think not. There are other lines of agricultural work in which freshman agricultural students as a class are more interested, and which can be taught satisfactorily without previous training in science. I refer to work in animal husbandry, such as stock judging and the study of market types and classes and breeding types and classes of live stock. This is a type of work that can be taught almost as satisfactorily to freshmen as to upper classmen because proficiency in the work is secured by practice and not by a study of the scientific principles underlying the work. It is a relief from the more detailed work over the microscope in botany or zoology and the extremely accurate work in chemistry or physics, and above all is work in which the average agricultural student is very much interested. A poll of the freshman class at our institution this fall showed that out of 175 students, 94 were especially interested and expected to major in animal husbandry, 20 in dairy husbandry, 18 in agronomy, 4 in horticulture, 4 in agricultural economics and farm management, while 35 were undecided as to the subject in which they would specialize. From the standpoint of student interest, animal husbandry would undoubtedly

be the best subject to offer at our institution during the freshman year, and a course in judging live stock is given to all freshmen in agriculture here.

Of what value is the second reason that is often advanced for requiring farm crops in the freshman year, namely, that it will interest students in the subject and in that way increase the number that may later specialize in the work? Perhaps to a certain extent it will serve this purpose, but can we afford to weaken the required course in farm crops for all agricultural students in order that a few may be induced to specialize in the work? Personally I think the course is weakened when taught in the freshman year without general botany as a prerequisite and that it should not be weakened for the majority for any supposed benefit that may be derived by the few who will later specialize in farm crops. The curricula in our engineering colleges are not arranged to permit each department of engineering to meet the men in the freshman year, neither do our medical colleges think it desirable to require obstetrics or pathology of the freshman students in order that more of them may specialize in these subjects later in their course. In the best engineering, medical and other technical schools, the courses are outlined to give the student as quickly as possible the necessary training in the sciences and to delay the technical work until the student is properly prepared for it. This should be our aim in agriculture.

Where for any reason it is thought wise to permit each agricultural department to offer some work in the freshman year in their respective fields, would not the best solution be a combined course in general agriculture for freshmen such as is offered by the Massachusetts Agricultural College, in which each department offers a certain portion of the work? Under this arrangement the students would all meet an instructor in farm crops and obtain an insight into the work, but would not obtain their real training in the subject until later in the course after they had taken the proper foundation courses in botany. It has always seemed to me, however, that a general course of this kind was a tremendous waste of time in view of the many other things that it would be desirable to have the student take, but which are crowded out because of lack of time. We have eliminated all courses of this kind at our institution but we give the students some help in vocational guidance by means of a series of weekly lectures during the first semester of the freshman year, given by the President, the deans of agriculture and extension, and the

heads of different departments in which the student may later take his major work.

Let us now consider the institutions that offer the required work in farm crops in the junior year. They are of two classes. First, those that do not offer general botany until the sophomore year and thus the work in crops is not given until after the student has had his botany; and second, those that require soils as a prerequisite for farm crops. I believe that nearly every one will agree that it would be desirable for the student to have a knowledge of soils before taking crops, but it is questionable if it is of sufficient importance to justify delaying the crops work until the junior year. Students in animal and dairy husbandry should have farm crops before taking Principles of Feeding, and it is certainly desirable to allow two years for elective work in farm crops for those students who expect to major in those subjects. It would seem to me, therefore, that for the best interests of all students the course in farm crops should be offered in the sophomore year and that general botany and chemistry should be required as prerequisites. If this is done, the department offering instruction in farm crops should have something to say regarding the type of work required of the agricultural students in botany. Too often the freshman students of agriculture are placed in the same botany classes with students from other colleges or departments and given work that may be desirable for a student that expects to major in botany, or perhaps pharmacy, but that is of much less value to the agricultural student. If the classes in botany are properly divided and the courses are planned along the lines of student interest, and if the right kind of botany is taught, it will furnish the proper foundation for the work in farm crops and should be required as a prerequisite for this subject.

THE STANDARDIZATION OF COURSES IN FIELD CROPS.[1]

JOHN B. WENTZ.[2]

In the last few years we have heard a great deal about the standardization of work in our educational institutions. There has been a tendency toward more uniform standards of requirements for entrance and for the amount and type of work required of students

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] Professor of Agronomy, Maryland State University, College Park, Md.

after entering the college or university. In years past it was common to look to certain outstanding colleges for high standards in certain phases of work. For instance, if one thought of studying animal husbandry there were one or two institutions in the country which stood out far above the others in work offered in this subject. If soils was the subject in mind probably it would be some other institution or if it was field crops probably another institution. This tendency to look to certain institutions as being the standards in particular phases of work probably always will exist, but at present there seems to be more of an effort to standardize the work in a certain subject in the various colleges of the country. In the fundamental sciences such as chemistry, physics, botany, and zoology we find that the undergraduate courses have been fairly well standardized. That is, we have freshman courses in chemistry which are pretty much the same in all of our State colleges and we have the freshman course in botany common to most of the colleges. These courses are offered in the same year and have very similar content. If a student tells you he has had freshman chemistry, you know about what chemistry he has had.

In some lines of agricultural work there has been considerable discussion on teaching methods and courses, and their content and objectives. The Association of American Agricultural Colleges and Experiment Stations has had a committee working along this line and in the reports of this committee are found some suggestions as to standardization of work in field crops as well as other agricultural subjects. The Society for Horticultural Science has for several years had a committee on courses of study. This committee has made reports to the Society which no doubt have had great influence in the standardization of courses in horticulture. Last June there was a conference at Lexington, Ky., of those interested in teaching soils, to make a study of what should be the nature of the beginning course in soils.

There are at least three different phases of this subject of standardization of course material which may be considered. The first of these, and the one which is introduced in this paper, is the uniformity of work offered by similar institutions; second, the division of subject matter between the departments of a single institution; and third, the division of subject matter into courses within a department so as to prevent duplication of material. The first of these phases of the subject is the most general in that it affects all the institutions in a common way. It is the phase of the subject which requires an

exchange of ideas between institutions and probably is the most logical point of attack in standardization, altho there will necessarily be some consideration, within institutions, of the other questions before this one can be properly disposed of. The proper division of subject matter between departments will be arranged within individual institutions but if anything standard is adopted as to the courses and their content in a certain subject the country over it must be done by the exchange of ideas between departments handling this work in the various institutions.

How far we can go in standardizing our agricultural courses may be questioned but we will all agree that a great deal could profitably be done in this direction. It would not be possible or even desirable for a group of authorities on field crops to get together and make up a definite list of courses and specify the content of these courses, the number of hours that shall be devoted to each course, and the year of the college curriculum in which they should be placed and say that each field crops department of the country should adopt this standard list of courses. This would be impossible because of the difference in crops grown in various States and the difference in types of farming. However, it seems that certain courses in field crops could be considered standard courses, at least for certain large sections of the country, and the content of these courses could be more or less standard.

One who has had the responsibility of organizing and carrying out or supervising teaching in field crops and who has given special attention to this phase of agronomic work realizes that there are numerous problems to be met. Some of these problems are common to other agricultural teaching or even to all teaching, while others apply especially to the subject of field crops. It is not the purpose of this paper to list these problems and suggest solutions, but merely to present a brief survey of course material in field crops now offered by the agricultural colleges of the country with a view to encouraging some thought on the question of standardization.

To get something definite in the way of a survey of present conditions a careful study was made of the catalog descriptions of courses now offered in field crops by the agricultural colleges. In most cases these descriptions were complete enough so that it was possible to get a fairly good conception of the subject matter covered by each of the named courses. A list was made of all the courses found; then, after studying the descriptions of these courses as they appeared in the various catalogs, they were classified under standard

names according to subject matter covered. The next question that was taken up was the year of the college curriculum in which these courses are placed. After the courses had been classified on subject matter it was determined from the catalogs what year each of these courses is offered by the different colleges and the number of credit hours set aside for each course.

After listing all the different names of courses it was found that there are now being offered in the United States 133 differently named courses in field crops. The average number of courses offered by a single college is 6 and a fraction, the maximum 21, and the minimum 2. By classifying these courses as far as possible on subject matter or content this number was reduced to 47. In Table 1 will be found names of courses which are offered by not less than three colleges, together with the number of colleges by which each course is offered. The course names in this table are the standard names assumed in classifying the courses as they appeared in the catalogs, arranged in order of the number of colleges by which they are offered. It probably would be possible further to reduce this number of standard courses by combining some of the courses as they have been listed in the table. For instance, there may be some different division or combination of the judging and grading work. However, in making up this list of standard names an attempt was made to classify the courses exactly on ground covered as described in the catalogs without leaving out any divisions or combinations of subject matter or making any new divisions or combinations.

TABLE 1.—*Courses offered by not less than three colleges, together with the number of colleges by which each course is offered.*

Forage Crops	36	Grain Judging	8
Crop Breeding	30	Small Grains	6
Field Crops, General	29	Cotton	6
Cereal Crops	24	Crop Rotations	4
Methods of Investigation	17	Weeds	4
Research and Thesis	16	Judging and Grading Field Crops.	4
Seminar	14	Grading Field Crops	3
Special Crops	10	Grain Grading	3
Seeds and Seed Testing	9	Special Problems in Crop Production	3
Corn	8		
Advanced Field Crops	8		

In Table 1 only 20 different courses appear, meaning that the remaining 27 are offered by less than three colleges. This indicates that even after classifying as far as possible the courses offered in

field crops, a large number of courses are offered by only one or two colleges. In a few cases there may be justification for the offering of a course in a certain college different from any course offered by any other college, but cases like this, it would seem, should be very few. If you give any weight to the votes of the colleges as indicated in this table, it seems that almost any field crops department should be able to select its courses from among this list of 20. This would reduce the number of courses in field crops in the country from 133 to 20.

Table 2 shows in what years each of the 20 standard courses are offered in the college curricula. In some of the catalogs it was not possible to determine in what year some of the courses are offered. In cases where it was stated that a course could be taken in either one of two or three years the earliest year was recorded.

TABLE 2.—*Year in which field crops courses are offered in the college curricula.*

Name of course.	Number of colleges offering in—			
	Freshman year.	Sophomore year.	Junior year.	Senior year.
Forage crops	1	12	16	5
Crop breeding			8	17
Field crops, general	12	9	3	3
Cereal crops	6	4	10	1
Methods of investigation			2	10
Research and thesis				14
Seminar			2	13
Special crops			1	3
Seeds and seed testing			3	2
Corn	2	1	3	2
Advanced field crops			1	5
Grain judging	2	2		2
Small grains	1	2	2	1
Cotton			1	5
Crop rotations				1
Weeds			1	2
Judging and grading field crops			1	1
Grading field crops			1	2
Grain grading			1	
Special problems in crop production				2

The outstanding thing in Table 2 is the irregularity in time at which some of the courses are offered. There are five courses out of the twenty which are offered in all the four years. It seems that there should be no reason why one college should offer cereal crops, for instance, in the freshman year and another college offer the same course in the senior year.

The purpose of Table 3 is to show the number of credit hours

devoted to the various courses by the agricultural colleges. In a few cases the number of hours was not given and these courses could not be represented in the table. In all cases the number of credit hours is on the basis of two semesters a year. Where the number of hours was given by terms in the catalogs they were reduced to semester credit hours and where fractions appeared the nearest whole number was used in the table.

TABLE 3.—*Number of hours devoted to the various courses in field crops by the agricultural colleges.*

Name of course.	Number of colleges offering—				
	1 hour.	2 hours.	3 hours.	4 hours.	5 hours or more.
Forage crops	1	8	21	2	4
Crop breeding		13	13	2	1
Field crops, general		4	10	6	7
Cereal crops	1	5	14	2	1
Methods of investigation	3	3	4	2	1
Research and thesis		1		6	5
Seminar	9	3		1	
Special crops	2	3	4		1
Seeds and seed testing	1	7	1		
Corn		6	2		
Advanced field crops		2	4	1	1
Grain judging	3	4	1		
Small grains		3	2		
Cotton		4	1	1	
Crop rotations	2	2			
Weeds	1	2			
Judging and grading field crops	1	2			
Grading field crops		2	1		
Grain grading		1			
Special problems in crop production			1		

A wide variation in the number of hours devoted to the various courses will be noted in Table 3. There may be some reason for this variation due to the difference in the relative importance of certain crops in different parts of the country but even here there probably could be more uniformity.

SUMMARY.

In general, there is a tendency on the part of educational institutions toward the standardization of work offered.

How far we can go in the standardization of courses in agricultural subjects may be questioned but certainly all will agree that a great deal could well be done in this direction.

At the present time there are listed in the catalogs of the agricul-

tural colleges of the United States 133 differently named courses in field crops. When these courses are classified according to ground covered the number is reduced to 47, and of these 47 only 20 are offered by more than one or two colleges.

Almost any field crops department of the country should be able to select all its courses from among this comparatively small group of 20.

Table 2 shows that there is great irregularity in the positions of the field crops courses in the college curricula.

Table 3 shows great variation in the number of hours devoted to the courses by different colleges. There is some excuse for this variation due to differences in importance of some crops in different parts of the country, but even here there probably could be more uniformity.

THE FIRST COLLEGE COURSE IN FIELD CROPS.[1]

WILLIAM L. SLATE, JR.[2]

At the Chicago meeting of the Society last November, a step toward better instruction in agronomy was taken when place on the program was given to a discussion of teaching problems in crops and soils. The direct stimulus had its origin in the conference on instruction in grain grading, held in Chicago the previous September. The idea bore fruit in the conference on instruction in soils at the University of Kentucky last summer and again in the arrangement of our present program.

The whole field of agriculture is relatively young and needs organization. Every department is an experimental center in teaching as well as research. Many avenues are open for the interchange of ideas on investigational problems and are well used, but the teaching phase has received less attention, altho we all agree as to its importance. It would seem, therefore, that this society has a definite function to perform in bringing about an exchange of opinions and ideas and perhaps even in laying definite plans, thru committees, for the study of teaching problems.

Last year the round table on "Teaching of Field Crops" brought

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] Agronomist, Connecticut Agricultural College, Storrs, Conn.

out very forcibly the fact that we are far from agreement in our basic points of view. For instance:

1. Is there a science of field crops, or is it an application of botany, entomology and the like?

2. If we recognize such a science, what is its relation to other subjects in the curriculum, particularly the pure sciences?

3. What technical knowledge and skill should be included in courses in crops?

These and many other questions were discussed without arriving at any definite conclusion or agreement. There is and always must be a variation in our teaching, based on region, college or university organization, and other local differences, but on the fundamentals there surely is some common ground.

The first course in field crops has been chosen for this discussion for several reasons:

1. The fundamental courses, required of underclassmen, should receive our very best efforts. On this I am sure we are all agreed.

2. Every agricultural graduate, no matter what his major, should be able to think intelligently in field crops. Therefore we commonly find at least one course in crops required of all students.

3. The more highly specialized courses will, in a way, take care of themselves

To discuss the subject intelligently, it is necessary to assume a point of departure, which may be stated as follows:

There is, in my opinion, a real science of field crops; in other words, a body of information that belongs to the subject. For the solution of many of the problems involved, or for the explanation of technic, other fields are drawn upon freely. This is common to all sciences. Chemistry calls upon physics and botany upon chemistry, but we do not consider botany as applied chemistry. In other words, field crops is not merely an application of the pure sciences. The problem is crop production, and we draw on other fields when there is need. For instances, I do not concede such a subject as agricultural botany. That phase of botany is included in field crops and horticulture. But for real botany there is an important place.

To illustrate—a farmer is producing tobacco. The control of Thelavia is a crops problem. Plant pathology has helped to solve it, but the farmer need not be a specialist in that subject to handle the disease successfully. In a course in crops, therefore, the control or practice should be taught, with just enough plant pathology to give the reason for the practice. This does not mean that a course in pure plant pathology would not be very valuable to the student, but it

should not be the so-called practical course. That phase should be covered in courses in crops and horticulture. With tnis viewpoint in mind a first course, called Field Crop Production, presents the following problems:

I. *Type of Course.* On this point, there is a divergence of opinion and practice. I submit that every agricultural graduate should have a general knowledge of crop production. The chief function of undergraduate courses is not to train specialists, but to give the student the general information necessary for farming and a broad outlook on agricultural problems. With this in mind, the course should include all the important crops with stress laid on those most important in the region.

II. *Aims of the Course.* The student should—

1. Be able to recognize the important field crops, plant and seed, and some varieties of those important in the region.
2. Know the simpler fundamental principles of plant growth.
3. Know good seed and how to get it.
4. Know cultural practices for the important crops. Here would be included control of diseases and insects.
5. Be able to lay out a cropping system for a given set of conditions.
6. Know something of the sources of information.

In fact, he should be able to think reasonably intelligently in field crops, to handle his crop successfully and know how and where to get help on special problems.

III. *Course Content and Method of Teaching.* This would naturally vary with the region, the season given, and the amount of time assigned. We are using a general text, Professor Montgomery's. Since forage is vital in New England agriculture, we have stressed meadows and pastures, but the most important features are the problems and the relation of the laboratory work to these problems. As an example, each laboratory section makes a study of four pastures. With this as a basis, they are given a problem which involves not only the information gained in the pasture study, but data that must be sought in the text and other sources.

Another feature we have found very useful is the "Term Problem." Near-by farms are chosen and for them cropping systems are planned. Many details are included, such as manure produced, seed used, machinery necessary, dates for various operations, disposal of crops, etc. This farm also serves as a basis for many minor problems in connection with the various crops studied.

IV. *The Relation to the Sciences and other Courses.* This phase

has been touched upon, but it might be well to emphasize the point that there need be no conflict. As to overlapping, it should be borne in mind that very few of us absorb an idea at the first presentation and that every problem has several sides, all of which must be seen before a full understanding is reached.

The friction arises when an instructor in crops spends a large amount of time teaching botany or plant physiology, thinking it necessary for a proper understanding of crop production, or when the course in botany dips into crop production as its chief source of subject matter. In neither case is this necessary. There is room for both.

V. *Relation to the Specialized Courses in Crops.* Here there should be no difficulty. If there is not enough material left after the first course is given, then we should give the one only. Since none of us would take this position, the general course should furnish the interest that will urge some students to pursue various phases further, but the attitude should not be one of proselyting. The value of the first course is lost when this is the aim. It should be kept in mind that we are training farmers first and specialists second and that the great majority of the student body will receive no further instruction in this subject.

VI. *Relation to Farm Experience and High School Agriculture.* This raises a variety of problems. In the States where the great majority of freshmen come from farms, many contacts and experiences can be omitted. The problem method can be even more emphasized, for the men have a farm background. Where high school agriculture is common it may be necessary to divide the class, or it is conceivable that students from certain high schools might be excused from this course.

VII. *Place in the Curriculum.* In the opinion of the writer, the course under discussion may be required in the freshman year. An objection is immediately raised, that of the botany prerequisite. In answer, let us suppose a group of farmers. Is it not possible to teach them the fundamentals of crop production without a previous course in general botany? It takes better teaching, to be sure, but it is being done. In the case of the student, botany following or paralleling this course serves as an elaborator, a clarifier.

By making this a freshman course, the student has his feet at once on solid ground. He begins with the fundamentals of his profession. In cases where farm experience is a prerequisite to admission or where practically all students are farm bred, such a course

might well be postponed until the sophomore year. In that case the type of course would be modified somewhat. This does not assume, however, that when given in the freshman year the course must be of high school caliber. It can be made a "man's job" without recourse to the extremely technical.

VIII. *Amount of Credit Allowed.* It is possible to teach the course in a single semester, by all means the fall in the north, allowing three hours' credit. Four or five credit hours would be much more satisfactory.

THE TEACHING OF SOILS IN AGRICULTURAL COLLEGES.[1]

W. H. Stevenson and P. E. Brown.[2]

The conference of soils teachers held in Kentucky last June is ample proof that the men who are responsible for the soils courses in the agricultural colleges of this country are determined to improve the teaching of soils of collegiate grade. This is a wise and timely decision for many reasons. During the past twenty-five years little or no organized effort has been made by our agricultural college teachers to outline and develop courses in soils that are reasonably uniform, that cover the whole field in logical sequence, that command and hold the interest of students, and that act as a challenge to really competent men to specialize in soils and pursue graduate study along this line. Even a superficial study of the soils courses that are outlined in many current college catalogs conclusively proves this statement.

At least a few of our agricultural college faculties apparently fail to look upon instruction in soils as worthy of a place of real importance in the curriculum. This attitude is no doubt due in part to the fact that in some colleges the soils work has not been presented in a forceful manner by competent teachers. But is not the real reason found in the fact that in many cases the instruction in soils does not measure up to the standard that it should have reached at this time, especially in the beginning or elementary courses? We may not agree on this point and it may not be important. However,

[1] Read by the senior author at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] The senior author is vice-director of the Iowa Agricultural Experiment Station and professor of farm crops and soils and the junior author is chief in soil chemistry and bacteriology, Iowa State College, Ames, Iowa.

we must agree that now is the time carefully to plan more satisfactory courses in soils for our agricultural colleges to the end that many well-founded criticisms of our present courses may be eliminated and soils work for students may be made more interesting and stimulating and truly helpful.

The status of the teaching of soils in a large number of our agricultural colleges seems to warrant the conclusion that more satisfactory results may be secured by uniting all phases of soils instruction in one organization or department. We do not believe that the student gets the best work in soils when the instruction in this subject is given by two or more collegiate departments. This arrangement almost invariably leads to overlapping in the courses and to a failure to obtain and hold the interest of the student. Experience teaches that only when all soils work for students is organized as a unit do we get the most satisfactory results in the outlining and development of courses and in creating an atmosphere that tends to make students become really enthusiastic about the study of soils.

Failure to organize the work on this unit basis is due almost entirely to the attitude of teachers of pure science and of administrative officers. Teachers of science are tempted to teach soils because this applied science opens a most interesting field that is naturally popular with students. The result of this attitude on the part of science teachers often leads to placing some of the work in soils in the chemistry or geology or some other department of the institution and in this way it is broken up and much is lost from the standpoint of unity, atmosphere, and appeal to the student.

Many administrative officers apparently do not fully grasp the idea that the science of soils is an applied science and is therefore a real unit. The science of soils is based on several pure sciences, chief among them being chemistry, physics, and bacteriology, but this is not a valid reason for considering soils a part of chemistry, a part of physics, a part of bacteriology, or a part of any other pure science. On the other hand it should be regarded as a definite applied science. In spite of this fact some college officials persist in the belief that certain phases of soils instruction should be given by one or more of the science departments, in most cases chemistry, and have not seen the necessity of uniting all phases of it in one organization. This has proved to be a real handicap in teaching soils in a satisfactory way and in not a few cases it has interfered to some extent with the development of experiment station work in soils.

Another factor that sometimes interferes with the normal develop-

ment of the soils courses in an institution is the fact that the teaching of soils is based too largely upon the local experiments. It is certainly true that the experimental data of any station should be of great value in connection with the instruction in that institution and should be utilized. In some cases, however, the courses in soils have been based so largely on the work of the local station and the problems of the State that time and opportunity have not been available for a consideration of some exceedingly important phases of the general subject of soils. For instance, so much time may be devoted to a classroom and laboratory study of the field experiments of a given station that the classes are cut off from a study of certain fundamental principles of fertility that are vastly more worth while.

Soils teachers must meet still other difficulties and problems. A list of four important problems includes the following:

1. The number and sequence of courses and the amount of work in each.
2. The subject matter presented in each course.
3. The character and amount of laboratory work.
4. The general method of presenting soils instruction to students.

A brief consideration of these problems shows, in the first place, that no college can teach the subject of soils properly in two or even three quarter or semester courses and yet some institutions offer little or no soils work beyond this limit. The results in these cases of course are wholly unsatisfactory from the standpoint of the student and the instructor. The student gets instruction in a very limited part of the subject of soils or he is confused and misled by a veritable jumble of facts and data concerning physics, fertility, manures, bacteriology, and possibly surveying and other subjects. The majority of our colleges, however, have made commendable progress in recent years in regard to the number of courses in soils that are offered.

We are of the opinion that not less than four or five courses, each running thru one quarter or term, should be required in a 4-year agricultural course in the case of students majoring in farm crops, soils, animal husbandry, farm management, or horticulture. These courses should include an introductory course dealing with soils in general and courses in fertility, manures and fertilizers, bacteriology, and management, offered in the order named. The work in soils for other students should be adapted as far as possible to meet their special needs; this applies to students in agricultural engineering,

dairying, forestry, agricultural economics, agricultural journalism, agricultural education, and in special lines such as combined courses in home economics and agriculture. Furthermore, it is not necessary nor desirable that the general agricultural student be required to take highly specialized and more or less technical courses in soils. Such courses should be offered as advanced electives which may be taken by those students who are preparing for positions that demand special soil training.

The nature of the subject matter in the general or required courses may be determined very satisfactorily by keeping in mind the fact that the general agricultural student should study those fundamental principles of soil science which will train him for any agricultural work and which will fit him to farm successfully. This means that the basic soil courses will deal not only with science as related to soils and the fundamental principles involved, but will also emphasize farm operations and farm practice. An extended experience has proved that the majority of students in our agricultural colleges are willing to dig for principles with great earnestness and enthusiasm when they know that these principles will be used in due time in the classroom or laboratory in working out practical, every-day problems of the farm. Certainly no teacher of soils in this day should hesitate to use practical illustrations and point out the application of principles to soil management problems. Failure to do this is not necessarily an earmark of superior scientific attainments and it may raise the question with some students as to whether or not the instructor is really competent to tie up the principles of soil science with practice. In this connection we would suggest that one of the real needs of soils teachers at this time is for text books for beginning students that do not attempt to cover the whole subject, but that deal fully and in a not too technical manner with one phase of the work. In case a book is offered that includes work in physics, fertility, manures and fertilizers, bacteriology, and management, or two or more of these subjects, it is desirable that each of these lines be treated as a unit. This arrangement will prevent confusion on the part of the student and will enable the teacher to present his work in the proper sequence.

We realize that the foregoing statements regarding the most satisfactory number of soils courses and the subject matter in each are too general to be of the greatest value. For this reason we present some facts about the soils work at the Iowa State College, with the hope that they may be of some value to soils teachers elsewhere and

may help to illustrate the points that we are endeavoring to emphasize.

It is worthy of note that the soils courses in Iowa have been developed gradually thru a period of eighteen years. They represent the efforts of a relatively large number of soils teachers who have endeavored earnestly to build up a group of courses that meet the requirements of about one thousand agricultural students, who hold widely different views regarding the amount and character of the soils work that should be included in their individual courses of study. On account of this attitude on the part of our students it is necessary in Iowa to offer courses in general soils, fertility, physics, manures and fertilizers, bacteriology, management, and surveying, including instruction that is quite elementary and also that which leads to the degrees of Master of Science and Doctor of Philosophy. The total annual student enrollment in these courses for the last eight or ten years, with the exception of the war period, has averaged approximately seven or eight hundred.

The introductory course at Iowa is called "Soils." Until two or three years ago this course was called Soil Physics and included rather general work along physics lines. The second course is known as "Soil Fertility" and not "Soil Chemistry." In our judgment the former name is much superior to the latter. The work in fertility may include a consideration of manures and fertilizers but here these subjects are taught in a third course called "Manures and Fertilizers." "Soil Management" is a final course for the general student. A brief course in "Soil Bacteriology" is offered as an elective preceding the work in "Soil Management." This is required for farm crops and soils students. In our judgment the first four courses represent the minimum amount of soils study that should be required of general agricultural students and we would make "Soil Bacteriology" an additional required course for farm crops and soils students.

Our first course, "Soils," includes a study of the origin, formation, and classification of soils. The soil provinces, regions, series, and types in the United States are considered and the purposes, methods involved, and value of a soil survey are taken up. This is followed by a more or less complete study of the soil areas, groups, and types in the State, utilizing our soil surveys as a basis. Special emphasis is placed on a study of the so-called abnormal soils of the State, such as the peat, alkali, gumbo, hardpan, and push soils. Soil erosion and its control, dry farming, and alkali soils are some of the special subjects which are touched upon briefly in this course.

The course in "Soil Fertility" begins with a study of the composition of soils in general, including a consideration of all plant-food constituents and compounds, available and unavailable plant food, the constituents necessary for plant growth, the chemical analysis of soils, its purpose and value, the elements likely to be lacking in soils, and the average content of agricultural soils in these constituents. This is followed by as complete a study as possible of the composition of the soils of the State. The principles of soil fertility are then presented broadly, special attention being devoted to the removal and return of plant food, the theories of a permanent agriculture, and the factors which are the basis of rational systems of soil management. Each of these factors is then studied in detail, with special emphasis on soil acidity and liming, phosphate fertilizers, organic matter, and nitrogen.

The course in "Manures and Fertilizers" includes a study of commercial nitrogen, commercial potassium, indirect fertilizers, and crop stimulants in relation to up-to-date systems of soil management. An extended study is made of complete commercial fertilizers, with special emphasis upon their place in the agriculture of the State. Farm manures and green manures are also studied and the course is concluded with a review of the principles that underlie field experimentation and a study of the data from the Iowa soil experiment fields.

The "Soil Management" course is naturally the culmination of the general soils work and is outlined so as to fix in the mind of the student the facts presented in the preceding courses. Approximately twenty-five actual farm problems are presented by the instructor, the student being required to hand in a written statement explaining in detail just how he would proceed to work out the problem under consideration on his own farm. These statements are then discussed, as far as time permits, in the class, for the purpose of pointing out errors and explaining practical methods of dealing with the problems on the farm. This course is one of the most popular in the institution and many students have said that it gives them just the type of information and training that they need along soils lines to prepare them for farming, teaching, county agent work, and similar activities.

The course in "Soil Bacteriology" includes a study of the numbers and kinds of bacteria in soils and their various activities, special emphasis being placed upon the relation of these organisms to the production of available plant food, the fixation of nitrogen, and their general relation to soil fertility and permanent agriculture.

Let us now consider briefly the laboratory work that is offered in connection with these courses. The laboratory method of instruction that has been followed quite generally in many institutions in recent years is undoubtedly open to severe criticism. No doubt it is time to revise much of the laboratory work in soils in order to make it fit in with the lectures and give the student a new body of facts, a new viewpoint, and provide him with useful information. Our experience proves that it is possible to give laboratory work in connection with the general soils courses that does not demand of the student an immense amount of uninteresting routine of more than doubtful value, such as is often carried on in connection with soil physics and soil fertility courses.

The laboratory work of our introductory course is based upon a study of the soils of the State as taken up in the soil survey reports. This is followed by field studies involving the actual preparation of a soil map of an assigned area and a study of the characters of soils in the field. Soil survey reports then serve as the basis for a specialized study of the soils of individual counties which are chosen to represent the large soil areas of the State. Discussions, quizzes, and the writing of reports make up this work. The field studies are carried out under the guidance of the instructor but the student is required to prepare his own map, describe all the soil types found, and prepare his report. The work as a whole is so arranged and handled that it is both interesting and instructive to the student. He acquires first-hand knowledge of soils and a broad viewpoint of the whole subject, besides gaining information which will be of great value to him when he returns to manage his home farm or when in some other capacity he is called upon to solve soil problems.

The laboratory work in soil fertility as offered in many institutions has been criticized, and when, as is true in many cases, it involves merely an analysis of fertilizers and soils, such criticism is warranted. In our institution the student's home farm forms a basis of the laboratory work in soil fertility. The purpose is to have each student plan a system of permanent fertility for his own soils. To do this he must know how much plant food the crops remove and what amounts are present in manures, fertilizers, and crop residues. To get this information he must make some analyses but the emphasis is of course placed upon the soil analyses. It is believed, however that a few typical materials should be analyzed. These analyses are clearly understood to be secondary to the main part of the work, which is the planning of a system of soil management for the farm.

Reports are required to be complete and recommendations accurate and the laboratory periods prove very profitable to the student.

· The laboratory work in manures and fertilizers is essentially the same as that in soil fertility. However, there is this difference. The former deals with soil management problems from the standpoint of a grain farm, the latter from the standpoint of a livestock farm.

The course in "Soil Management" does not include laboratory work. In soil bacteriology, laboratory work may or may not be included. The laboratory course as given in Iowa includes a counting of numbers of bacteria and a measurement of the ammonifying, nitrifying, deodifying, and azofying power of soils. Soil from the student's home farm is secured when possible and the work is then much more satisfactory. As in other courses, the emphasis is placed upon the interpretation of the results and not upon the mere securing of them, for the real value undoubtedly lies in such interpretation.

The advanced courses in soils may be variously outlined and may be arranged to fit local or curriculum conditions. Opportunity should undoubtedly be offered, however, for electives in soil physics, soil fertility, soil bacteriology, and soil surveying. There should also be seminars and courses dealing with special problems. In Iowa courses are offered under the following names: Soil Physics; Advanced Soil Physics; Advanced Soil Fertility; Advanced Soil Bacteriology; Dry-Farming Soils; Soil Mycology and Protozoology; Soil Surveying; Advanced Soil Surveying; Special Problems in Soil Physics, Fertility, Bacteriology, or Surveying; Advanced Special Problems in each of these lines; Junior and Senior Seminars; and Theses. Graduate courses leading to the degrees of Master of Science and Doctor of Philosophy are also offered in Soil Physics, Soil Fertility, Soil Bacteriology, Soil Humus, and Soil Management. All these courses except those especially designed for graduate students are carefully and definitely outlined for class use and so arranged as to give the student excellent training in the particular subjects that he may pursue. The graduate work of course is outlined for each individual student and is highly specialized.

The teaching of soils to undergraduate students may certainly be made interesting and highly effective if it is properly organized, if courses are offered that are wisely outlined, if laboratory work is given that deals primarily with problems of scientific and practical interest, and if competent instructors are secured who never lose sight of the fact that soil science is a practical, applied science which must be presented to the student in a way that will enable him to secure a definite understanding of soil principles as applied to farm problems.

THE TEACHING OF SOILS.[1]

M. F. MILLER.[2]

Three papers have appeared recently in the JOURNAL of this Society having to do with the teaching of soils. The tone of these papers indicates a general feeling that improvement in methods of teaching have not kept pace with the advancement in soil science. It seems that we have reached a point where very definite steps should be taken to put the subject upon a more satisfactory teaching basis, and to consider the needs of students as well as the relation of the subject matter to that of other agricultural courses.

You are doubtless aware that as a result of the publication of the above mentioned papers a few of the interested men took the initiative in calling a conference of soils instructors for the purpose of comparing ideas and arriving at some fundamental principles which might be rather generally applicable. A brief report of the findings of this conference was published by the secretary in the last issue of the JOURNAL[3] of this Society, and some brief notes regarding it appeared in the last issue of *Soil Science*.[4] I wish therefore to consider some of the findings and conclusions of this group of men representing unofficially, yet rather directly, the membership of this Society.[5]

It might be said with reference to the nature of this conference that it was very informal. No papers were presented, altho an outline to guide discussion had been prepared. The conference continued thru two days, thus giving ample time for full and careful discussion of the various questions involved. In was considered best to confine the discussions at this first conference largely to the introductory soils course, its prerequisites, its place in the curriculum, its content, and its arrangement. The conclusions, therefore, have to do

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] Professor of Soils, University of Missouri, Columbia, Mo.

[3] Conference on elementary soils teaching. *In* JOUR. AMER. SOC. AGRON., 12: 211–214. 1920.

[4] Notes on the conference on elementary soil teaching, held at Lexington, Kentucky, June, 1920, *by* P. E. Karraker, secretary. *In* Soil Science, 10: 247. 1920.

[5] Professor Miller was chairman of this conference.—Ed.

with this course alone. I shall attempt to give the viewpoint of the majority of the men present upon the most important of these considerations, which are as follows.

1. The introductory college course in soils should be a uniform course to be required of all agricultural students, and it should carry approximately five semester-hours credit or the equivalent.

The desirability of an introductory course of a general nature seemed to meet with almost universal approval. At present there is a wide variation in the character of the introductory soils courses. Some deal largely with soil physics, some with soil chemistry, while still others cover a rather broad field in a somewhat superficial manner. Such a difference in character is due partly to different local conditions, partly to prevailing interests of the instructors, and partly to the comparatively recent development of soil science. It would seem, however, that the science has now reached a condition in which the giving of such a general course is feasible, and that the character of this course should be similar to those introductory courses offered in the pure sciences.

It is believed further that soils is one of the fundamental subjects, regarding which all students should have a general knowledge regardless of the lines in which their specialization may fall. If this is the case it should be required of all students. While the length of such a course would necessarily vary somewhat in different institutions, it seems probable that a five semester-hour course, or its equivalent, would be sufficient to cover the field.

2. This course should deal largely with the scientific principles underlying successful soil management in general, with such practical applications as local conditions demand. The name of the course, where a descriptive name is required, should be "The Principles of Soil Management."

It is realized that exact standardization of such an introductory course is impossible, yet the subject matter should be as uniform as the conditions in the various institutions will allow. It should deal with principles, yet it should include such applications as will illustrate points under consideration and give the student a knowledge of how these principles are related to practice. Local conditions will determine the amount of such practical applications which should be included. One fault of many beginning courses has been that they have been arranged with the idea that the student will take further work in the subject. Under such a plan the general body of students, most of whom take little or no advanced work in that subject,

has been given too little attention. Certainly an introductory course in soils designed for training agricultural students, particularly where such a course is prescribed, should give the student a general knowledge of the field. Such a plan seems not only good pedagogy but good departmental ethics.

With such a fundamental general course there is little danger of degeneration into an indefinite discussion of prevailing methods of practice. In dealing with fundamental principles the course may be maintained of high collegiate grade, comparable to the introductory courses in pure science, yet containing such applications to practice as will be of value to the student who goes into practical fields. However, the character of the material presented should not be such as to emphasize solely the economic importance of soil management. While this is the thing which is commonly uppermost in the minds of farm-reared students, the teacher should at times get above purely economic considerations and emphasize the importance of soil knowledge to civilization as well as point out the broad relations of the subject to general science.

3. The subject matter of the course should be presented by well correlated recitation, lecture, and laboratory work.

I think we will all agree that in most instances the subject matter given in technical agricultural courses lacks somewhat in definiteness and in pedagogic arrangement. As a general rule agricultural instructors are not well trained in pedagogy, and under the rapid development of soil science many instructors lack proper technical preparation. Nevertheless much improvement has been made in recent years. The introduction of standard texts has been very helpful. With a greater differentiation of work in agricultural colleges it has been possible for men to narrow their fields of endeavor and increase their efficiency. It seems therefore that the time is ripe for a thorogoing revision of the subject matter in such courses as the one under discussion.

As a basis for discussion the five semester-hour course was taken as probably the most common, and an effort was made to reach an agreement regarding the division of time between lecture, laboratory, and quiz periods. Naturally, considerable differences of opinion developed with reference to this matter. There were two suggested plans. First, the plan of three recitation periods and two laboratory periods per week; second, the plan of three lecture periods, one quiz or recitation period, and one laboratory period. The first plan is probably the most common in those institutions now giving a general

introductory course. It was the opinion of the conference, however, that this is not the best arrangement. There is the danger that when as much as two laboratory periods per week are included this time will be taken up very largely either with physical experiments of doubtful value or with chemical work in which the students are more impressed with the technic of the operation than with the fundamental facts which these chemical manipulations are designed to establish. It is believed that the average student would secure much more value from the course if the laboratory exercises were designed to give definite information. A general course in soils should teach soils and not chemistry or laboratory technic. There are of course institutions where the soils work is organized with that of agricultural chemistry in which the laboratory instruction might best consist largely of quantitative chemical determinations, but is seems doubtful if such an amount of chemical work is fair to the general student. Such work had best follow in elective courses.

The plan of three lectures, one quiz, and one laboratory period per week met with the more general approval. The introduction of the quiz period is in line with plans of teaching introductory courses in the pure sciences. The purpose of this quiz is to clear up doubtful points in the minds of students, and to emphasize important phases of the subject, as well as to determine the accuracy of the students' knowledge. The subject of soils, when properly taught, is complex and difficult. Quizzes of such a nature that the student is caused to think and to arrange the facts he has gathered would seem to be proper pedagogy. This is particularly true of a general course of this character offered early in the curriculum.

The lecture method supported by a standard text is much preferred to the use of a text alone or lectures alone. The text adds to the material given in the lectures and students should be held accountable for the subject matter in each.

The laboratory or practicum work for a single period per week needs special consideration. In the first place no work should be offered in the laboratory or practicum, the principles of which have not already been covered in the class room. Secondly, as has been suggested, the material presented in the laboratory should be such as to impart helpful information directly, rather than indirectly thru complicated laboratory exercises which are of value mainly to the soils specialist. It is doubtless on this part of the content of the course that there will be the greatest difference of opinion. In order to provide a workable scheme of rather general application the

conference spent a considerable period in preparing such an outline. This outline includes such subjects as the following:

a. Study of minerals and rocks, and methods of weathering.
b. Study of soil particles and soil classes.
c. Determination of certain physical properties of soils, such as volume weight, porosity, etc.
d. Study of soil organic matter.
e. Determination of field moisture.
f. Study of soil reaction.
g. Study of fertilizer materials and lime.
h. Certain field trips for studying soil formation, soil classes and types, and the use of fertilizer and lime.

It is realized that such an outline is merely suggestive and time only will determine its value. Doubtless experience will suggest many changes. It does, however, give a working plan for trial and includes exercises which, where properly handled, will give the student information of value.

4. The minimum prerequisites of this course should be one year of general inorganic chemistry, one term of general geology, and either high school or college physics. Wherever practicable the work should be offered in the sophomore year.

It is desirable that some information on soils be available to students early in the course as a foundation for such subjects as field crops and horticulture. If the list of prerequisites be extended much beyond those mentioned, the work could not be offered before the junior year. Furthermore, for such a course as outlined these prerequisites are all that are absolutely necessary, altho it is realized that more are desirable. The importance of placing the course as early as the sophomore year seems to outweigh that of fuller fundamental training.

The advantages of such a general introductory course as outlined are obvious. It would enable the general student to obtain in a single course a survey of the entire field. It would make possible a better standardization of subject matter, of texts, and of laboratory material. It would allow a fuller application of the principles of pedagogy and would facilitate the transfer of credits from one institution to another. It is of course realized that the universal adoption of such a course is impracticable, but there seems little reason why it should not come into rather general use. Certainly the trend seems to be in this direction in the larger institutions. The conference agreed that the plan suggested should be given trial in as many institutions as could make the proper arrangements and that another meeting should be held a year or two hence to discuss developments.

I think I agree in general with the various recommendations of this conference. They certainly look toward improvement. There are, however, certain matters which the conference did not consider but which seem important.

I am of the opinion that much of the loose teaching which has been done in agricultural colleges, not only in soils but in other lines of agricultural instruction, has been due to the scheduling of too many courses. There is naturally a desire on the part of every department head to popularize his work and appeal to students. Often this results in multiplying courses. In the more wealthy institutions, well supplied with instructors, this may be justified, but where the instructor's time must be extended over a number of courses, efficiency in teaching is certainly lessened. I am convinced that a few courses in which the subject matter is well worked out and pedagogically arranged will give best results. Where certain specialized courses are really needed, these usually can be offered in alternate years rather than every year. Such a plan saves the instructor's time and increases efficiency.

There is another obstacle to thoroly successful teaching which seems to me is common in many institutions and that is the interference of experiment station work and the general routine of office work with which many instructors are charged. My experience has been that teaching is the project most likely to be slighted. Men go before a class with little preparation. Some institutions have met this difficulty by forming separate station staffs, altho in the weaker institutions such a plan is rarely possible and there is some doubt in my mind as to its wisdom. With the increasing numbers of students, however, I take it that such a division of work will become more common. But for those men who must work under a dual or triple responsibility much care and labor is necessary that the subject matter of their courses be properly arranged and presented.

It has always seemed to me that the average agricultural college instructor takes particular satisfaction in minimizing the value of pedagogy in teaching, or at least he is very sceptical of its value. Doubtless some of this has resulted from the intricate systems of pedagogy taught in many departments of education and in teachers' colleges, but much of it is due to a lack of any knowledge of pedagogy on the part of the instructors themselves. There are, of course, exceptionally effective teachers who know little pedagogy and doubtless in some lines (rarely in agriculture) there are those who give too much attention to methods and too little to the preparation of

good subject matter, but certainly the teaching of soils in our colleges of agriculture would profit greatly by the application of the more important principles of psychology and pedagogy. In the University of Missouri the Dean of Agriculture has insisted that young instructors take one or more courses in the School of Education. Possibly this same plan is being followed in some other institutions. In my judgment, satisfactory soils teaching from this time forward will be based, not only upon a thoro training in soil science, but on such a knowledge of pedagogy as will enable the instructor to present the material to the best advantage. I believe the time is ripe for placing the teaching of soils, particularly the introductory courses, on a sound pedagogic basis.

Finally, it seems to me that the relation of soils courses to others in the curriculum should be given more consideration. Every one who has had experience in arranging curricula realizes that there are many diverse interests and almost every curriculum is a compromise. Nevertheless there are certain principles which it would seem might meet with more or less general approval. Mention has already been made of the fact that some knowledge of soils is desirable in the teaching of field crops and horticulture. To these might be added farm management, agricultural engineering, and even certain courses along animal lines. It would certainly seem unwise, therefore, to postpone the first soils course until the junior year. It is of course possible to give elementary instruction in this subject in the freshman year, and I think some institutions have provided for this in order to pave the way for other courses. Such a plan does not seem advisable, however, since with so little fundamental training on the part of the students the work would be largely of secondary school character. The compromise of a sophomore course, as suggested by the conference, seems best.

Where institutions offer a general introductory course in field crops there seems to be no plan of universal adaptation which will allow soils work to precede it. Some colleges are offering this course in the freshman year, others in the sophomore year. In the latter case the soils work may precede, or run parallel with it, according to the methods of scheduling and sectionizing the classes, but it seems clear that in many cases the introductory course in field crops must be given without a knowledge of soils on the part of the students. Where such a course consists partly of the principles of crop production it seems almost imperative that the work include something regarding soil tillage and seed-bed preparation of import-

ance in the production of each crop. For the farm-reared student who is familiar with the practical handling of soils such soil principles will be quite readily grasped without a previous course in soils, but the city-reared student is at a decided disadvantage. It would seem the part of wisdom for the instructors in soils and field crops to cooperate closely in the work of handling both these introductory courses. While the crops instructor may be compelled to use considerable soils material, the soils instructor must to a certain extent draw on crops subject matter as well.

There are other courses commonly offered in soils and crops in which an overlapping of subject matter is necessary. In fact, these two lines are so closely allied that entire separation, with the exception of a few specialized courses, is impossible. In courses dealing with production the two subjects must merge. Such courses are commonly listed under such titles as soil management, field crop management, and crop rotation. Certainly in all such courses the subject matter of soils and crops must be to a considerable extent combined. Unless the instructors cooperate closely and arrange the subject matter of the courses carefully, repetition is unavoidable. Worse than this, conflict in statement of fact or contradictory recommendations are almost certain to be made. This is one of the inevitable results of extended specialization and it should be corrected. In general our courses have profited greatly by restricting the field of the instructor and it is the duty of department heads to avoid in so far as possible the difficulties which arise. It is only thru such watchfulness on the part of these men and thru close cooperation on the part of instructors that the greatest efficiency of instruction may be attained.

THE INTRODUCTORY COURSE IN SOILS.[1]

A. B. BEAUMONT.[2]

The content of the laboratory work usually forming a part of the introductory course in soils as given in our agricultural colleges has quite appropriately been questioned. Incidentally the content of the entire course and methods of presentation have come in for discussion, but the nature of the laboratory work seems to be the bone of contention.

From the papers[3] presented in the JOURNAL of the Society, there appear to be at least two schools of thought on the subject; first, those who would limit the laboratory work to operations which the student will be using, or at least which will be of direct value, in post-graduation activites, and second, those who would have the laboratory work include, in addition to the utilitarian exercises, those which may enlarge the student's vision and stimulate his interest. These remarks apply to the so-called average 4-year student who has only an average interest in soils and not to one who is specializing in the subject.

An analysis of the possible values of the laboratory study of soils indicates at least six possibilities. They are:

1. To acquaint the student with materials.
2. To teach soil science.
3. To teach principles involved in soil investigations and in soil management.
4. To ascertain definite information concerning specific soils.
5. Formal discipline.
6. To arouse and stimulate interest in soil science.

The first group of possibilities resides first in those exercises in which one studies materials such as soil classes and fertilizing materials with the obvious aim of becoming familiar with them and,

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 18, 1920.

[2] Professor of Soils, Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass.

[3] Karraker, P. E., What is the value of the usual laboratory work given in general soils courses? *In* JOUR. AMER. SOC. AGRON., 11: 253–256. 1919.

Buckman, H. O., The teaching of elementary soils. *In* JOUR. AMER. SOC. AGRON., 12: 55–57. 1920.

Smith, R. S., Introductory courses in soils. *In* JOUR. AMER. SOC. AGRON., 12: 58–60. 1920.

second, in exercises in which the avowed aim is something else, but in which the unavoidable handling of materials forces familiarity.

Among the latter may be mentioned the study of specific gravity and hygroscopic moisture. This group also merges into the second, in which the principal aim is the study of soil science. In this second group we have such exercises as the study of mineral constituents, soil separates, the colloidal state, hygroscopic moisture, etc.

The study of principles of soil investigations and soil management includes exercises in mechanical analysis and estimation of organic matter and lime requirement. The importance of these exercises lies not in the accuracy of manipulation or fineness of detail, but in the clear demonstration of the principles involved. It seems that some teachers have missed or lost sight of this important point. It is quite possible for a student to become bewildered by details and thus miss the fundamental principles involved or, figuratively speaking, he is unable to see the woods because of the trees.

The ascertaining of definite information concerning specific soils, especially those brought from home by the student, certainly lends interest to the student's work. However, beyond narrow limits it is a questionable procedure pedagogically and, from the standpoint of direct use of student's results in 90 percent of the cases, it is worthless. Bear in mind that we are speaking of the introductory course in soils.

For formal mental discipline it seems that some of the more difficult laboratory exercises with soils would serve as well as any laboratory work. But the formal discipline theory of education as usually ascribed to John Locke has fallen into disrepute from which probably it will not be resurrected.

From the standpoint of arousing and stimulating interest in soil science a great many laboratory exercises may be justified that could not be approved from the standpoint of the student's post-graduation activities. This is indeed worth while because it is from this class of undergraduates that most of the future agronomists will be recruited. Who can forecast the ultimate results from the stimulation of a student's interest in soil science by a properly conducted exercise on the colloidal condition of soils or absorption of plant food by soils?

A course in soils that limits subject matter to that which the student apparently will use in post-graduation activities is short-sighted and nonprogressive. Such is the character of the education of primitive peoples. The history of education[4] shows that progress really

[4] Graves, F. P., A Student's History of Education, p. 12. Macmillan, 1916.

began with the education of the individual beyond his immediate personal needs. Thus the Athenians are cited as a notable example among the first peoples to make their education progressive.

Our graduates, even those who are to deal with practical applications only, must have information beyond what is needed for everyday activities if they are to be able to grow and to measure up to opportunities. They must have vision as well as a reserve of information. After graduation they should not be forced to work up to their capacity at all times. There should be for them an academic margin of safety. This is especially necessary for those who may engage in teaching or research.

Recently we heard a leading agronomist, a director of one of our leading experiment stations, say to a group of county agents and extension workers who were thirsting after the science of soils and crops, that it is well for one to have a few hypotheses and theories, even heresies, tucked back in his head, for one never knows when they may be convenient in helping explain things otherwise inexplicable.

In connection with the strictly laboratory course above discussed there should be well correlated field work consisting of observations and problems in soil management. Such field work will tend to show the student the practical application of his studies, arouse his interest, introduce problems, and give him practice in applying his knowledge.

Of course, many will admit the value to be derived from most of the exercises usually presented. The point of disagreement is in regard to the proper balance. The recommendations of the recent conference of soil teachers is a step in the right direction.

It appears that laboratory demonstrations by the instructor should be given more importance than they have been. By the use of demonstrations many of the more difficult exercises can be given in a shorter time and at less expense without impairing their pedagogical value, and thereby save time for field work and problems in soil management.

The above remarks apply to courses for 4-year college students. For our 2-year and other short course students the same general principles apply with modifications. In general the exercises in which the student is getting practice for post-graduation activities should be magnified at the expense of the others. There should be more field work and more problems in soil management.

THE MICHIGAN PLAN FOR DISTRIBUTING IMPROVED CROP VARIETIES.[1]

J. F. Cox.[2]

Widespread interest is at present being manifested in organized movements to obtain the extensive distribution of dependable seed of high yielding crop varieties. Crop improvement associations, experiment associations, and corn growers' associations have been organized in many States for this purpose. With the formation of the International Crop Improvement Association marked impetus has been given to this work.

Within a short time there should develop a more or less standardized method of State organization for the purpose of distributing improved varieties, as a result of the interchange of ideas among representatives of States engaged in this work.

Recent progress along the lines of testing, developing, increasing, certifying, and distributing seed of improved varieties in Michigan may therefore be of some interest to agronomists in States where such work is contemplated or under process of development.

Several important changes in the plan of obtaining rapid distribution of dependable varieties have been made during the past year and have greatly increased the effectiveness of this work in Michigan. The initial distribution of varieties to members of the Michigan Crop Improvement Association is no longer made in small lots of from several pounds to a bushel, but means have been provided for the growing of large increase fields on the Experiment Station Farm which will make possible the distribution of substantial quantities of seed at cost to members of the association.

The field inspection system has been placed on a definite basis thru the action of the directors of the Crop Improvement Association in fixing the responsibility for the direction of this work with the Farm Crops Department of the Michigan Agricultural College, the cost being borne by the association.

Seed certification and guarantee is made by the Certification Committee of the Crop Improvement Association, based on recommenda-

[1] Contribution from the Michigan Agricultural College, East Lansing, Mich. Received for publication December 18, 1920.

[2] Professor of Farm Crops. Michigan Agricultural College.

tions made by field inspectors. In addition to the field inspection a careful analysis and germination test is made of thrashed samples of seed.

Perhaps the most important step in the development of the machinery of distributing improved crops was brought about in Michigan thru the establishment of the Farm Bureau Seed Department on April 1, 1920, with J. W. Nicolson, former secretary of the Michigan Crop Improvement Association, as manager.

The sale of seed produced and certified by the Crop Improvement Association is made thru the Seed Department of the Farm Bureau or directly by growers. The secretary of the Michigan Crop Improvement Association (A. L. Bibbins, extension specialist) is therefore left free to devote his energies to the proper development of the association, to registration and inspection of seed, etc. This plan greatly enlarges the demand for improved varieties and places quantity sale in the hands of a specially created department, properly equipped with machinery for cleaning and shipping.

Briefly outlined, the plan for accomplishing the development, testing, increasing under inspection, and sale of seed of improved varieties in Michigan is as follows:—

1. *The Michigan Agricultural College, Farm Crops Department, Experiment Station and Extension:*

a. Varietal testing. Extensive varietal tests of all major crops, including standard and new varieties, are maintained at the experiment stations at East Lansing and Chatham, and also at numerous points over the State on a cooperative basis.

b. Plant breeding. Pure-line selection and hybridization work with practically all crops adapted to Michigan. The following varieties as listed by Prof. F. A. Spragg have been contributed by the plant-breeding work during the past ten years: Worthy oats, 1911; Rosen rye, 1912; Red Rock wheat, 1913; Michigan Winter barley, 1914; Robust beans, 1915; College Wonder and College Success oats, 1916; Wolverine oats, 1917; Michigan 2-Row and Michigan Black barley, 1918; and Michigan hardy alfalfa, 1919.

c. Corn improvement. The local adaptation of varieties is established by varietal tests. Field selection and intensified selection by the ear-row method is carried on at the experiment station and at points over the State with leading varieties. In lower Michigan counties the Duncan, Silver King, Early Reid and Leaming are standard varieties; in central Michigan the Golden Glow and Pickett, and in northern Michigan the early Golden Glow and Early Pickett.

d. Large increase fields on the station farm make possible rapid and safe distribution. Properly handled increase fields are highly important in securing effective distribution of new varieties.

e. Extension specialists and county agents aid in securing widespread use of varieties of proved worth.

2. *The Michigan Crop Improvement Association* (Secretary's Office, East Lansing, Mich.), an organization of farmers who are interested in crop improvement thru growing better varieties and the use of better cultural methods. A number are interested in the commercial production of high-grade seed. The association functions as follows:

a. Seed of improved varieties is distributed to members from the Farm Crops Department increase plats.

b. Record of distribution and transfer of varieties kept by the Secretary.

c. Field inspection and thrashed grain inspection supported by the association under the leadership of the Farm Crops Department.

d. Certification of seed which attains the high standards required is made by the Certification Committee. Certification is based on reports submitted by inspectors.

3. *The Michigan Farm Bureau Seed Department* (Headquarters at Lansing, Mich.). This organization is authorized to sell certified seed produced by the Michigan Crop Improvement Association.

a. A central warehouse has been established in Lansing fully equipped with adequate seed cleaning apparatus. A service charge is made for seed handled.

b. County Seed Departments, under the direction of the State Seed Department, have been formed in 32 counties, and are being organized rapidly in remaining counties.

c. In addition to the seed produced by the Crop Improvement Association, the Farm Bureau Seed Department also arranges for the purchase direct from growers of northern-grown alfalfa seed and for the extensive sale both in and out of the State of Michigan-grown clover, vetch, peas, beans, etc.

This new development in the field of seed distribution is proving to be a marked step forward in securing the widespread use of high yielding varieties of adapted crops over large areas. The standardzation of crop production along proper lines is being followed by a noticeable improvement in market quality.

AGRONOMIC AFFAIRS.

THE SYMPOSIUM ON AGRONOMIC TEACHING.

The program of the annual meeting of the American Society of Agronomy at Springfield, Mass., in October, 1920, consisted of symposia on two subjects, agronomic teaching and liming. The six papers which made up the first of these symposia are printed in this issue. Those on liming will follow in early issues, after which the papers included in the symposium on corn improvement at the December meeting of the Society in Chicago will be published. On several previous occasions, papers on teaching soils and crops have been printed in the JOURNAL, but never before has so much material on this subject been brought together in a single issue. No more important subject can be considered by agronomists, for it involves not only the training of our agricultural college graduates who are to be our farm leaders in coming years, but of our future investigators and teachers of agronomy. Such papers as those printed in this issue form the best evidence of the usefulness of the American Society of Agronomy.

MEMBERSHIP CHANGES.

The membership reported in the January JOURNAL was 551. Since that report was written the Society has enjoyed a healthy growth, and it is particularly encouraging to report that of the 81 members then reported as lapsed 15 have been reinstated. In nearly every case, these men have paid both 1920 and 1921 dues. During the month, 6 resignations have been received and 3 names not previously included in the lapsed list have been reported, while 25 new members have been recorded. These changes make a net increase of 31 and a total membership of 582.

THE CHICAGO MEETING.

A special meeting of the American Society of Agronomy was held in the Botany Building of the University of Chicago on the thirteenth anniversary of the founding of the Society, December 31, 1920, in connection with the meeting of the American Association for the Advancement of Science. The program was a symposium on the subject,

"Our Present Knowledge of Methods of Corn Breeding," prepared under the leadership of Prof. H. K. Hayes of the University of Minnesota. On the previous afternoon, the Society united in a joint session with the Botanical Society of America and the American Phytopathological Society. The programs of the two meetings follow.

Joint Session, Thursday, December 30, 2.00 p. m.

Recent Investigations on the Black Stem Rust of Wheat and Other Grains, by E. C. Stakman, Minn. Agr. Expt. Sta., St. Paul, Minn.

Plants and Plant Culture, by C. V. Piper, Bureau of Plant Industry, Washington, D. C.

Natural Vegetation and Agriculture in Africa (illustrated), by H. L. Shantz, Bureau of Plant Industry, Washington, D. C.

Friday, December 31, 9.00 a. m.

The Experimental Basis for the Present Status of Corn Breeding, by F. D. Richey, Bureau of Plant Industry, Washington, D. C.

The Bearing of Modern Genetic Studies on Corn Breeding, by R. A. Emerson, Cornell University, Ithaca, N. Y.

Corn Breeding as a Hobby, by H. A. Wallace, Wallaces' Farmer, Des Moines, Iowa.

Progress Report on the Methods of Selection in Self-Fertilized Lines (illustrated), by D. F. Jones, Conn. Agr. Expt. Sta., New Haven, Conn.

Overcoming "Root-Rot" by Breeding, by W. D. Valleau, Kentucky Agr. Expt. Sta., Lexington, Ky.

Friday, December 31, 2.00 p. m.

Ear Type Selection and Yield in Corn (illustrated), by T. A. Kiesselbach, Neb. Agr. Expt. Sta., Lincoln, Neb.

Progress Report on Corn Disease Investigations (illustrated), by James R. Holbert, Bureau of Plant Industry, Bloomington, Ill.

The Present Status of Continuous Selection Experiments with Corn, by L. H. Smith, Illinois Agr. Expt. Sta., Urbana, Ill.

First Generation Varietal Crosses, by Fred Griffee, Minnesota Agr. Expt. Sta., St. Paul, Minn.

The Relation of Weather to Rust Epidemics, by H. L. Walster, N. Dak. Agr. Expt. Sta., Agricultural College, N. Dak.

NOTES AND NEWS.

F. G. Bamer, assistant agronomist at the Pennsylvania station, has resigned to engage in commercial work.

F. C. Bauer, who has been engaged in graduate study at the University of Wisconsin, is now extension agronomist in soils at the University of Illinois.

R. K. Bonnett, formerly professor of farm crops, has been made professor of agronomy in the reorganization of the soils and crops work at the University of Idaho. G. R. McDole, formerly of the Minnesota college and station, and H. W. Hulbert have been made assistant professors and F. L. Burkhart, field superintendent.

T. S. Buie, formerly agronomist at the Georgia station, has been appointed specialist in fertilizer investigations at the Pee Dee Substation, Florence, S. C.

A. C. Dillman, for the past several years engaged in forage-crop breeding in the office of alkali and drought-resistant plant-breeding investigations of the Federal Department of Agriculture, has been transferred to the office of cereal investigations and placed in charge of the flax project.

P. L. Gaddis, professor of agronomy and agronomist at the Nebraska college and station, has resigned to take charge of a farm in Custer Co., Nebr.

Ralph Kenney, formerly extension agronomist at the Kansas college, is now extension specialist in agronomy at the University of Kentucky.

C. Larsen, director of extension in South Dakota, has been given a year's leave of absence to become director of the dairy products marketing department of the Illinois Agricultural Association. W. F. Kumlein, county agent leader, will be acting director of extension.

E. F. Ladd, president of the North Dakota college, was elected to the United States Senate at the November elections.

K. C. Livermore, professor of farm management at Cornell University, has been granted a year's leave of absence to engage in farming.

R. B. Lowry is now instructor in soils at the University of Tennessee.

Fred G. Merkel has resigned his position at the Massachusetts station to become assistant professor of soil technology in the Pennsylvania college.

P. H. Rolfs, for the past several years director of the Florida station, resigned December 31 to accept a commission to locate, establish, and conduct an agricultural institution in the State of Minas Geraes, Brazil. The president of the State desires that the heads of all departments shall be American scientists.

R. E. Stephenson is now assistant soil chemist at the West Virginia station.

W. W. Weir, formerly assistant professor of soils in the University of Wisconsin, is now editorial manager for the Soil Improvement Committee of the National Fertilizer Association.

D. C. Wimer, formerly assistant professor of soil technology in the Pennsylvania college, has resigned to accept a position along similar lines in the University of Illinois.

The agricultural building at the Alabama Polytechnic Institute at Auburn was entirely destroyed by fire on October 17. Included in the property burned were the college and station library and some valuable botanical collections.

The National Academy of Sciences and the National Research Council have obtained a site for their new building in Washington, for which funds have already been donated. It will face the new Lincoln Memorial when erected, the site just purchased at a cost of about $200,000 being the block between B and C streets and 21st and 22d streets northwest. The funds for the purchase were obtained from contributions made by a large number of persons.

Science contains an interesting statement of doctorates conferred by American universities in 1920, with tabulations showing the number of such degrees conferred by each university, the subjects in which the degrees were granted, and other information, including the names of those receiving the degrees and the titles of the theses. Of the 328 doctorate degrees granted in 1920, the University of Chicago leads with 59, followed by Cornell University with 35, Harvard with 28, and 28 other institutions with smaller numbers. When classified according to subjects, chemistry is far in the lead, with 96, botany ranking second with 47. In agriculture, 8 doctorate degrees were conferred, 3 each by Cornell and Wisconsin and 1 each by Illinois and Minnesota. The recipients of the doctorate degrees in agriculture were: From Cornell University, Roy Glen Wiggans, Daniel Scott Fox, Frank App; from the University of Illinois, Jose J, Mirasol; from the University of Minnesota, Paul Harmer; from the University of Wisconsin, Wm. Merriott Gibbs, Tsunao Inomato, Frederick C. Bauer.

JOURNAL

OF THE

American Society of Agronomy

Vol. 13. MARCH, 1921. No. 3

THE SYMPOSIUM ON LIMING.[1]

C. V. Piper.

The effects of liming in relation to soil quality and crop yields are varied and complex, a matter that needs to be borne in mind constantly when interpreting the results of experiments or field trials. The statement most commonly used in farm articles is that lime "sweetens the soil," a phrase that is alluring and probably overemphasizes only one effect of lime. It is well to remember that limestone soils are proverbially rich, but there are exceptions, as in the chalk soils. The papers presented in the symposium did not cover all of the phases of lime in relation to soil changes and crop yields and it therefore seems desirable to introduce the papers with a brief synopsis of the definitely known facts and the more or less controversial problems in regard to the agricultural use of lime. These may be presented in a series of statements with brief comments.

1. Lime is a necessary element of food to all plants but some kinds utilize it in much larger proportion than others. Some species, like alfalfa, red clover, and beets, seem to require larger amounts than others in their physiological processes. For certain other plants like rhododendrons too much lime is deleterious. On the basis of their normal relation to lime content of soil, botanists have classed plants as calciphiles or lime-lovers and as calciphobes or calcifuges or lime-haters. Many species however seem relatively indifferent. There is yet doubt as to whether these evident relations and reactions

[1] This brief introduction to the series of papers on liming presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920, has been prepared by the associate editor for crops, Prof. C. V. Piper, agrostologist in charge of the Office of Forage Crop Investigations, U. S. Department of Agriculture, Washington, D. C.

are quantitative with respect to lime or qualitative in regard to toxicity or acidity. This phase of lime relations was not specifically presented in the symposium.

2. Lime changes the reaction of the soil with reference to "acidity" and toxicity, and these affect favorably the yield of most but not all crops. Several papers discuss this relation of lime.

3. Lime accelerates the process of nitrification especially by free-living organisms. The increased amounts of nitrates formed betters the yield of most crop plants, and this effect must needs be differentiated from other factors associated with lime. This function of lime is stressed in some of the papers. Additional information, however, is needed in regard to possible long-time effects of continued liming on the nitrogen and humus content of a soil.

4. Lime affects various chemical reactions of the mineral constituents of the soil, thus changing their solubilities. One paper relates to these phenomena.

5. Lime modifies the physical texture of the soil, a subject not discussed specifically. In considering this effect of lime it is well to bear in mind that 1 ton per acre is less than 1 ounce to a square foot of surface. The flocculating effect of lime on clays is well established. Its supposed binding effect on sandy soils is not definitely determined. Also the indirect effects of liming by increasing crop residues, especially of clovers and grasses, together with increased liberation of CO_2, materially affect soil structure.

6. Lime modifies the abundance of some parasitic fungi. In some cases the disease is prevented or minimized, as in club root of cruciferous plants; in others it is accentuated, as in potato scab. This was not considered in any of the papers.

7. Loew's contention that a particular ratio of lime to magnesia is important for most crop plants is still a subject of controversy. One paper deals more or less directly with this subject.

8. The effects of lime in practical use vary both with the physical and chemical natures of the calcareous material used. Three of the papers are devoted to phases of these effects.

THE FUNCTION OF CALCIUM IN THE NUTRITION OF SEEDLINGS.[1]

RODNEY H. TRUE.[2]

LIMITS OF THE PAPER.

In the beginning of this discussion I wish to call attention to the limits which bound it. It deals with seedlings of various crop plants grown in water cultures which were usually kept in darkness when not under observation. However, in several cases similar experiments carried on in the light gave results essentially similar to those seen in experiments carried on in darkness. The methods used, the sources and the magnitude of recognized errors are not dealt with, having been discussed previously elsewhere.[3]

The principles developed here are applied with caution to plants not studied, as unexpected specific and racial peculiarities have been found. This paper presents only results of work in which the writer has been directly concerned, usually in association with colleagues, and no attempt is made to review the work of others.

THE PROBLEM STATED.

The results here reported have come from an attempt to ascertain more clearly the nature of the indispensable work done in green

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920. Contribution from the University of Pennsylvania, Philadelphia, Pa. The observations here recorded were made while the writer was employed in the Bureau of Plant Industry, United States Department of Agriculture, as physiologist in charge of Plant Physiological Investigations. The formulation of these results has been made since his transfer to the University of Pennsylvania.

[2] Professor of botany and director of the botanical garden, University of Pennsylvania, Philadelphia, Pa.

[3] True, Rodney H. and Bartlett, Harley Harris. Absorption and excretion of salts by roots, as influenced by concentration and composition of culture solutions. I. Concentration relations of dilute solutions of calcium and magnesium nitrates to pea roots. U. S. Dept. Agr., Bur. Plant Indus. Bul. 231. 1912.

True, Rodney H. The harmful action of distilled water. *In* Amer. Jour. Bot., 1: 255–273. 1914.

True, Rodney H. and Bartlett, Harley Harris. The exchange of ions between the roots of *Lupinus albus* and culture solutions containing one nutrient salt. *In* Amer. Jour. Bot., 2: 255–278. 1915.

plants by calcium in the most commonly utilized combinations, and thus to learn why land must contain lime or some other compound containing the calcium ion. The writer realizes the great reach of the problem and contributes this as a report of progress.

METHODS USED.

Seedlings of crop plants obtained by germinating the seeds in clean sphagnum were grown in beakers of slowly soluble glass containing culture solutions made up with carefully prepared distilled water which was usually made in a laboratory containing no gas, in which heat was obtained from electric heating coils. Culture solutions were made up with the best salts obtainable purified by further treatment when it seemed necessary. The concentration of these solutions during experiments was measured by the resistance offered to the passage of the electric current measured by the usual telephone method. Considerable changes in concentration were assumed to be due to the taking in or giving out of ions by seedlings. The duration of an experiment was determined by the food reserve in the seed.

SEEDLINGS IN DISTILLED WATER.

When lupine seedlings are grown in distilled water the following result appears with considerable regularity. During the first period, lasting from 4 to 6 days, the distilled water increases steadily in concentration due to the giving off of ions to the solution by the roots of the plants. It is likely that these ions are in part due to the CO_2 given off by the respiring seedlings. These saturate the solution, which finally reaches a concentration in equilibrium with the CO_2 content of the air. After this initial period, the concentration of the distilled water usually continues approximately the same with minor changes until the seedlings begin to deteriorate. Then the tissues apparently become more permeable, or interior breakdown liberates a greater quantity of ions which pass into the solution. The concentration then shows a decided increase which grows as injury involves additional cells.

SEEDLINGS IN RIVER WATER.

As ordinary river water is a good culture medium for seedlings, tests were carried out in water from the Potomac River.[4] At the

[4] Composition of Potomac River water, as determined by Outwater, is reported by Parker, H. N., Willis, Bailey, Bolster, R. H., Ashe, W. W., and Marsh, M. C. The Potomac River Basin. Water Supply and Irrigation Paper 192: 297. U. S. Geol. Survey. 1907.

time these samples were taken this water had a usual composition which gave a resistance corresponding to a $37N \times 10^{-4}$ solution of KCl. From the day on which the seedlings were placed in it, the concentration rapidly decreased on account of the active absorption of ions by the roots of the seedlings. This continued until the concentration of the river water fell below that at which an equilibrium is reached in distilled water. In the mixture of ions contained in Potomac water absorption exceeded leaching to such an extent that at the end of the experiment the river water contained approximately as many ions as a good (but not excellent) grade of distilled water.

Seedlings in Cane-Sugar Solutions.

In order to ascertain whether the difference in the behavior of the seedlings observed in distilled water and in Potomac water was due to the osmotic properties of the dissolved material present in the latter, solutions of cane sugar were made up in distilled water with an osmotic value equal to that of the river water. Seedlings placed in the sugar solutions behaved essentially like those in distilled water. The ions given off to the medium greatly exceeded in quantity the number that might possibly have been absorbed. It appears clear, therefore, that Potomac water differed from distilled water in its essential physiological properties because of the inherent nature of the dissolved material rather than because of the mere fact of the number of ions and molecules present.

Seedlings of Lupinus albus in Solutions Containing Single Salts.

Since it appeared that the behavior of seedlings in these solutions depended on the chemical qualities of the ions present, a series of experiments was carried out in which the ions commonly recognized as essential to plant development were dissolved in distilled water. The concentrations offered to the seedlings usually ranged from a very small ion content (8 to 20 gm. normal in a million liters) to that ordinarily reached in the soil solution of a rainy climate (200 to 500 gm. normal in a million liters).

1. Potassium salts.

In solutions containing potassium salts, seedlings of the white lupine (*Lupinus albus*) behaved very much as they did in distilled water and rarely made a net absorption.

In Table 1 are shown the original concentrations of potassium-containing solutions offered to the seedlings, the concentration of

these solutions at the time when absorption was greatest, and the day on which maximum absorption was noted.

TABLE 1.—*Absorption by seedlings in solutions of potassium salts.*

Salt.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).	Day of maximum absorption.
KCl	32	101	−79	11th
	96	152	−56	10th
	160	210	−50	9th
	224	272	−48	12th
	288	302	−14	14th
	352	391	−39	10th
	416	442	−26	14th
Distilled water	0	80	−80	14th
K_2SO_4	20	32	−12	11th
	60	68	− 8	12th
	100	107	− 7	11th
	160	160	0	11th
	200	192	+ 8	11th
	240	242	− 2	11th
Distilled water	0	17	−17	12th
KH_2PO_4	32	108	−76	10th
(Calculations assume ionization into K and H_2PO_4 ions.)	64	128	−64	15th
	96	144	−48	12th
	176	204	−28	10th
	208	300	−92	13th
Distilled water	0	87	−87	15th
K NO_3	32	101	−69	16th
	96	155	−59	13th
	160	188	−28	13th
	224	207	+17	14th
	288	272	+16	15th
	352	339	+13	12th
	416	423	− 7	14th
Distilled water	0	80	−80	15th

The rate of absorption seemed to be greatest after the tenth day shortly before the deterioration of the seedlings set in. A very slight net absorption was registered in stronger solutions of K_2SO_4 and in KNO_3, but in no case did it become greater than about $13N \times 10^{-6}$, a quantity ranging in magnitude with the quantity of ions likely to be found in good distilled water. It is also to be noted that absorption was distinctly greater in the nitrate series than in any other.

2. MAGNESIUM SALTS.

Similar cultures were set up in solutions containing magnesium ions. Here, two new features appeared. After a day's loss of ions, the seedlings began to make a marked absorption which continued

for several days before deterioration occasioned a rapid leakage of ions. In some of the more concentrated solutions injury and leakage began to appear several days earlier than was usual in other cultures. Table 2 shows a part of the data.

TABLE 2.—*Absorption by seedlings of white lupine in solutions of magnesium salts.*

Salt.	Original concentration $(N \times 10^{-4})$.	Concentration at time of maximum absorption $(N \times 10^{-4})$.	Absorption or leach $(N \times 10^{-4})$.	Day of maximum absorption.
$MgSO_4$	12	26	−14	13th
	60	48	+12	13th
	96	83	+13	10th
	144	134	+10	8th
	168	153	+15	7th
Distilled water	0	18	−18	10–13th
$Mg(NO_3)_2$	8	10	− 2	13th
	32	9	+23	13th
	64	45	+19	11th
	104	94	+10	10th
Distilled water	0	10	−10	11th

The tendency of the seedlings to absorb more from the nitrate solution than from others noted in the case of the potassium series is again seen.

3. CALCIUM SALTS.

Cultures containing calcium salts showed active absorption in all concentrations except from those so dilute that the unavailable minimum was soon reached. Data are given in Table 3.

CONCLUSIONS.

Certain definite results seemed to come from these experiments with white lupines in solutions of single salts.

(1) Since in solutions of but one K-containing salt absorption of electrolytes equals loss, it appears clear that the $\dot{K}$ ion is not absorbed in considerable quantity.

(2) When the $\overset{+}{K}$ ion is accompanied by the $\overset{-}{NO_3}$ anion, absorption slightly exceeds loss in a number of the higher concentrations.

(3) When the $\overset{+}{K}$ ion is accompanied by the $\overset{--}{SO_4}$ ion and by the $\overset{-}{H_2PO_4}$ ion, leach greatly exceeds absorption. Since the behavior of KH_2PO_4 in the solutions here given may not be accurately represented in our calculations it is quite possible that the facts are not correctly presented here. However, the main fact just stated seems to be plain.

(4) Solutions of magnesium salts are clearly absorbed, whether the $\overset{++}{Mg}$ ions are accompanied by $\overset{-}{NO_3}$ ions or by $\overset{--}{SO_4}$ ions. This absorption tho well defined in all except the most highly dilute solutions is limited and injury to the seedlings soon appears. $\overset{++}{Mg}$ ions altho absorbed seem to be toxic even when much diluted.

(5) Solutions containing calcium compounds are actively absorbed by the white lupine whether the $\overset{++}{Ca}$ ions be accompanied by $\overset{--}{SO_4}$ or $\overset{-}{NO_3}$ anions. The $\overset{++}{Ca}$ ion seems to be chiefly responsible for this absorption.

TABLE 3.—*Absorption by seedlings of white lupine in solutions of calcium salts.*

Salt.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).	Day of maximum absorption
$CaSO_4$	12	11	+ 1	12th
	60	11	+49	15th
	84	33	+51	14th
	120	76	+44	15th
	168	116	+52	16th
Distilled water	0	14	−14	7th
$Ca(NO_3)_2$	8	5	+ 3	10–12th
	16	5	+11	14th
	48	17	+31	12th
	56	32	+24	14th
	96	59	+37	13th
Distilled water	0	12	−12	12th
$Ca(NO_3)_2$	20	13	+ 7	10–12th
	60	30	+30	15th
	100	50	+50	14th
	160	97	+63	15th
	220	130	+90	15th
	240	182	+58	13th
Distilled water	0	33	−33	15th

ACID LAND PLANTS AND NON-ACID LAND PLANTS.

Experiments carried out with various crop plants show that the lupine is fairly representative of a group associated in practice with sandy, usually acid lands. To this group belong the peanut, white dent Indian corn, and alsike clover.

Contrasted with this group is another characteristic of richer soils which usually contain a greater proportion of lime. To this group belong the squash, soybean, red clover, and apparently the sweet corn of the gardens.

Squash Seedlings in Solutions of Calcium Salts.

Squash seedlings showed marked differences in behavior in different solutions of calcium salts, apparently being strongly influenced by the anion as well as by the $\overset{++}{Ca}$ ion. $CaCl_2$, $CaCO_3$, and $Ca(NO_3)_2$ were absorbed in similar degree by squashes, $CaSO_4$ to a much less extent. This situation is illustrated by Table 4, made from data worked out in large part by Dr. Rodney B. Harvey.[5]

Table 4.—*Absorption by seedlings of Early Prolific Marrow squash in calcium solutions.*

Salt.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).
$Ca(NO_3)_2$	24.5	34.0	− 9.5
	63.0	34.6	28.4
	96.3	34.0	62.3
	182.6	29.6	153.0
	351.8	39.1	312.7
	518.5	47.8	470.7
	693.5	125.9	567.6
	867.0	152.9	714.1
Distilled water	11.7	50.0	−38.3
$CaCl_2$	15.7	26.5	−10.8
	75.3	20.5	54.8
	116.5	19.7	96.8
	384.0	32.3	351.7
	582.4	141.1	441.4
Distilled water	8.0	45.0	−37.0
$Ca\ SO_4$	15.6	50.0	−34.4
	52.1	37.7	14.4
	101.9	76.0	25.9
	319.1	251.5	57.6
	535.4	448.1	87.3
	824.4	704.6	119.8
Distilled water	10.0	45.0	−35.0

It will be noted that absorption from the nitrate and chlorid solutions increases with the concentration offered, the unused surplus remaining relatively small, while in the case of the sulfate the reverse is seen, the unused surplus increasing as the quantity offered increases. The $\overset{--}{SO_4}$ ion seems to be clearly responsible for this result.

Let us now compare the behavior of the white lupine with that of the squash. We see that while absorption from both calcium-containing solutions is relatively small in the case of the lupine, absorption from the $Ca(NO_3)_2$ solution is approximately like that from the

[5] True, R. H., and Harvey, R. B. Absorption of calcium salts by squash seedlings. *In* Brooklyn Bot. Garden Memoirs, 1: 502–512. 1918.

$CaSO_4$ solutions. With the squash, absorption from the $CaSO_4$ solution is roughly the same in quantity as that seen in the lupine. When however the $\overset{++}{Ca}$ ion is accompanied by either the $\overset{-}{Cl}$ or the $\overset{-}{NO_3}$ anion, absorption is very much greater.

In this connection it should be noted that the lupine is an acid-loving plant of the most pronounced type grown usually on thin sandy soils in which the soil solution may be expected to be distinctly poor in the nutrient ions and perhaps rather dilute under usual weather conditions. The squash, however, is a garden plant grown best in rich soils in which the soil solution is likely to carry much more material, including sufficient calcium.

Similar experiments carried out with several species of plants seem to show that these plants are representative of two strongly marked physiological types. Acid-land crops like the white lupine, field corn (Boone County White), alsike clover, and peanuts absorbed relatively sparingly from all Ca-containing simple solutions and took up approximately as much from the sulfate solutions as from the nitrate solutions. Garden plants and field crops requiring rich soils were found to absorb much greater quantities from calcium solutions than the other group, except when the $\overset{++}{Ca}$ ion was accompanied by the $\overset{--}{SO_4}$ ion. To this group of strong-feeding Ca-loving plants belong the marrowfat squash, soybean, red clover, and sweet corn (Country Gentleman?).

SEEDLINGS OF LUPINUS ALBUS IN SOLUTIONS CONTAINING TWO SALTS.

In view of the fact that in nature plants that succeed in living must absorb more than they lose and must absorb ions that are not taken up from these simple solutions it seemed likely that the behavior of plants toward these ions might be modified by the presence of still others. We have already seen evidence pointing in this direction in the marked influence of the presence of the $\overset{--}{SO_4}$ ion on the absorption from calcium-containing solutions.

Consequently solutions of nutrient salts were prepared in which different pairs of salts were mixed. Seedlings of *Lupinus albus* were used. It has been shown in the above experiments with single salts that both kations and anions exert a pronounced influence on absorption. It was desired first to study especially the seedlings of the $\overset{+}{K}$, $\overset{++}{Mg}$, and $\overset{++}{Ca}$ ions, and in order to stabilize the influence of the anions as much as possible, nitrates were used in all cases.

I. MIXTURES OF $Ca(NO_3)_2$ AND KNO_3.

Four groups of mixtures were prepared ranging in total salt content from 120 to 480 gram-normal in a million liters. In each group were five solutions in which the salts named appeared in the following proportions: 4/4 KNO_3; 3/4 KNO_3, 1/4 $Ca(NO_3)_2$; 2/4 KNO_3, 2/4 $Ca(NO_3)_2$; 1/4 KNO_3, 3/4 $Ca(NO_3)_2$; and 4/4 $Ca(NO_3)_2$. In Table 5 are shown for each mixture (1) the original concentration, (2) concentration at time of maximum absorption, and (3) quantity absorbed or leached out at that time.

TABLE 5.—*Concentration changes caused by white lupine seedlings in mixtures of KNO_3 and $Ca(NO_3)_2$.*

Solution.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).	Day of maximum absorption.
4/4 KNO_3	120	132	−12	10
3/4 KNO_3 1/4 $Ca(NO_3)_2$	120	98	22	10
2/4 KNO_3 2/4 $Ca(NO_3)_2$	120	86	34	11
1/4 KNO_3 3/4 $Ca(NO_3)_2$	120	66	54	12
4/4 $Ca(NO_3)_2$	120	68	52	12
Distilled water	0	25	−25	10
4/4 KNO_3	240	274	−34	11
3/4 KNO_3 1/4 $Ca(NO_3)_2$	240	173	67	14
2/4 KNO_3 2/4 $Ca(NO_3)_2$	240	167	73	12
1/4 KNO_3 3/4 $Ca(NO_3)_2$	240	133	107	14
4/4 $Ca(NO_3)_2$	240	185	55	11
4/4 KNO_3	360	368	− 8	7
3/4 KNO_3 1/4 $Ca(NO_3)_2$	360	291	69	11
2/4 KNO_3 2/4 $Ca(NO_3)_2$	360	258	102	14
1/4 KNO_3 3/4 $Ca(NO_3)_2$	360	202	158	14
4/4 $Ca(NO_3)_2$	360	288	72	9–11
4/4 KNO_3	480	463	17	11
3/4 KNO_3 1/4 $Ca(NO_3)_2$	480	370	110	11
2/4 KNO_3 2/4 $Ca(NO_3)_2$	480	348	132	12
1/4 KNO_3 3/4 $Ca(NO_3)_2$	480	342	138	14
4/4 $Ca(NO_3)_2$	480	384	96	10–12

Certain general results appear to be clearly marked. (1) Absorption from the simple solutions tends to become greater as the concentration of the solution increases. (2) Absorption from mixtures is always greater as the proportion of $Ca(NO_3)_2$ in the mixtures increases, the most favorable ratio in all total concentrations being 1/4 KNO_3, 3/4 $Ca(NO_3)_2$. This is equivalent to saying that while KNO_3 alone can not be absorbed by white lupine seedlings under the conditions here seen, a greater quantity of ions is absorbed from the mixture because a small proportion of KNO_3 is present.

In but one instance ($240N \times 10^{-6}$ ¾ KNO_3, ¼ $CaNO_3$) was the absorption equal to the quantity of $Ca(NO_3)_2$ put into the solution when it was made up. It is therefore impossible to say that the presence of the $\dot{\dot{C}}a$ ion has caused the absorption of the KNO_3, since the total absorption might possibly have come from the $Ca(NO_3)_2$ component. On the other hand the fact that absorption is greatly increased and sometimes nearly doubled when ¼ of the $Ca(NO_3)_2$ is replaced by an equivalent quantity of KNO_3 argues strongly for an absorption of the latter component.

2. MIXTURES OF $Mg(NO_3)_2$ AND KNO_3.

Mixtures of $Mg(NO_3)_2$ and KNO_3 similar to those just noticed were prepared and planted with lupine seedlings. The results of this experiment are shown in Table 6.

TABLE 6.—*Concentration changes caused by Lupinus albus seedlings in mixtures of $Mg(NO_3)_2$ and KNO_3.*

Solution.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).	Day of maximum absorption.
4/4 KNO_3	120	137	−17	6
3/4 KNO_3 1/4 $Mg(NO_3)_2$	120	105	15	8–10
2/4 KNO_3 2/4 $Mg(NO_3)_2$	120	98	22	8
1/4 KNO_3 3/4 $Mg(NO_3)_2$	120	88	32	10
4/4 $Mg(NO_3)_2$	120	83	37	9–10
Distilled water	0	28	−28	8
4/4 KNO_3	240	240	0	7–8
3/4 KNO_3 1/4 $Mg(NO_3)_2$	240	196	44	11
2/4 KNO_3 2/4 $Mg(NO_3)_2$	240	218	22	8
1/4 KNO_3 3/4 $Mg(NO_3)_2$	240	193	47	12
4/4 $Mg(NO_3)_2$	240	208	32	10–11
4/4 KNO_3	360	357	3	8
3/4 KNO_3 1/4 $Mg(NO_3)_2$	360	324	36	8
2/4 KNO_3 2/4 $Mg(NO_3)_2$	360	325	35	13
1/4 KNO_3 3/4 $Mg(NO_3)_2$	360	333	27	7–8
4/4 $Mg(NO_3)_2$	360	357	3	3
4/4 KNO_3	480	470	10	8
3/4 KNO_3 1/4 $Mg(NO_3)_2$	480	451	29	8
2/4 KNO_3 2/4 $Mg(NO_3)_2$	480	440	40	11–12
1/4 KNO_3 3/4 $Mg(NO_3)_2$	480	470	10	6–7
4/4 $Mg(NO_3)_2$	480	462	18	7

1. It will be noted that while in the simple solutions of KNO_3 there is a slight tendency for net absorption to take place in the more concentrated solutions, in the simple solutions of $Mg(NO_3)_2$ the absorption, while never very considerable, tends to become less as the concentration is increased.

2. In the mixtures a somewhat greater absorption is usually found than in the simple $Mg(NO_3)_2$ solution, but this difference is not very great, and no clearly favorable proportion appears. Thus the presence of the $\overset{+}{K}$ ion may facilitate slightly the absorption of the $\overset{++}{Mg}$ ion or vice versa.

3. MIXTURES OF $CA(NO_3)_2$ AND $MG(NO_3)_2$.

A third series of mixtures made up and tested in the above manner dealt with $Ca(NO_3)_2$ and $Mg(NO_3)_2$. It will be noted however that proportions are so modified as to show the effect of small quantities of $Ca(NO_3)_2$. The absorption data at the time of its maximum are shown in Table 7.

TABLE 7.—*Concentration changes caused by white lupine seedlings in mixtures of $Ca(NO_3)_2$ and $Mg(NO_3)_2$.*

Solution.	Original concentration ($N \times 10^{-6}$).	Concentration at time of maximum absorption ($N \times 10^{-6}$).	Absorption or leach ($N \times 10^{-6}$).	Day.
4/4 $Ca(NO_3)_2$	120	53	67	16–17
2/4 $Ca(NO_3)_2$ 2/4 $Mg(NO_3)_2$	120	52	68	13–14
1/4 $Ca(NO_3)_2$ 3/4 $Mg(NO_3)_2$	120	50	70	13
1/10 $Ca(NO_3)_2$ 9/10 $Mg(NO_3)_2$	120	72	58	12
4/4 $Mg(NO_3)_2$	120	111	9	10–13
4/4 $Ca(NO_3)_2$	240	121	119	16–17
2/4 $Ca(NO_3)_2$ 2/4 $Mg(NO_3)_2$	240	126	114	15
1/4 $Ca(NO_3)_2$ 3/4 $Mg(NO_3)_2$	240	145	95	13
1/10 $Ca(NO_3)_2$ 9/10 $Mg(NO_3)_2$	240	180	60	15–16
4/4 $Mg(NO_3)_2$	240	235	5	9–12
4/4 $Ca(NO_3)_2$	360	203	157	18
2/4 $Ca(NO_3)_2$ 2/4 $Mg(NO_3)_2$	360	160	200	17
1/4 $Ca(NO_3)_2$ 3/4 $Mg(NO_3)_2$	360	237	123	17
1/10 $Ca(NO_3)_2$ 9/10 $Mg(NO_3)_2$	360	233	127	16–17
4/4 $Mg(NO_3)_2$	360	350	10	10–12
4/4 $Ca(NO_3)_2$	480	293	187	17–18
2/4 $Ca(NO_3)_2$ 2/4 $Mg(NO_3)_2$	480	284	196	16–17
1/4 $Ca(NO_3)_2$ 3/4 $Mg(NO_3)_2$	480	279	201	15–17
1/10 $Ca(NO_3)_2$ 9/10 $Mg(NO_3)_2$	480	315	165	16–17
4/4 $Mg(NO_3)_2$	480	495	−15	5

1. It seems to be generally true that in solutions of weak total concentration absorption from unmixed $Ca(NO_3)_2$ solutions is almost as great as it is in mixtures containing a portion of $Mg(NO_3)_2$. In the higher total concentration a clear tho not great increase comes with the presence in the solution of equal parts of the two salts.

2. *When the proportion of $Ca(NO_3)_2$ is further reduced, absorption falls off when the proportion of $Ca(NO_3)_2$ to $Mg(NO_3)_2$ becomes 1 to 9.*

3. It appears, however, that the presence of $\overset{++}{Ca}$ aids the absorption of other ions since absorption is relatively much greater than the quantity of $\overset{++}{Ca}$ ions present. In almost all cases, the quantity of ions absorbed is in excess of the quantity of the calcium put into the solution, and in the more dilute mixtures and those in which the proportion of Ca salt is small, it is much in excess.

RESULTS IN NITRATE SOLUTIONS DISCUSSED.

As a result of the experiment with pairs of nitrates it appears probable that the presence of $\overset{++}{Ca}$ ions in mixtures with either potassium or magnesium nitrates secures an increased absorption of the ions of the latter salts. Such an interaction in mixtures of magnesium and potassium nitrates was not clearly seen.

When the nitrates mentioned are offered in pairs in solutions varying from $120N \times 10^{-6}$ to $480N \times 10^{-6}$, the seedlings of the white lupine absorb more electrolytes than they do from unmixed solutions of the salts concerned.

In mixtures of $Ca(NO_3)_2$ and KNO_3, the deterrent action of $\dot{K}$ ions on absorption is seen in the high ratio of Ca to K required to give maximum absorption, viz, 3 Ca to 2 K. The value of a small quantity of $\overset{+}{K}$ ions is however proved by the excess of absorption in a mixture containing them over that from a simple $Ca(NO_3)_2$ solution. The absolute quantity of Ca present in the mixtures seems to be of great influence for, as the proportion of Ca increases in the dilute solutions, absorption is increased. The favorable action of $\overset{++}{Ca}$ ions is therefore striking in mixtures as well as in pure solutions.

In mixtures of $Ca(NO_3)_2$ and $Mg(NO_3)_2$ the greatest absorption was found in the ratios 2 Ca:2 Mg or 1 Ca:3 Mg. The great significance of even a small proportion of Ca is seen in a relatively high absorption made in a mixture containing 1 Ca to 9 Mg.

In mixtures containing $Ca(NO_3)_2$ and KNO_3 and in those containing $Ca(NO_3)_2$ and $Mg(NO_3)_2$ it seems likely that the presence of the $\overset{++}{Ca}$ ions increases the absorption by the seedlings of the ions of the other salts, i.e., $\overset{++}{Ca}$ ions seem to aid the absorption of $\overset{++}{Mg}$ and of $\overset{+}{K}$ ions. Such an effect was not seen in the mixture containing $Mg(NO_3)_2$ and KNO_3.

SEEDLINGS OF LUPINUS ALBUS IN SOLUTIONS CONTAINING THREE SALTS.

It has been found practicable to bring crop plants to a fairly normal maturity in three-salt mixtures to which a suitable source of iron has been added. Our next experiment was planned to test the effectiveness of more complicated mixtures but in such a way as to secure further data if possible on the influence of the commoner nutrient cations: $\dot{\dot{Ca}}$, $\dot{\dot{Mg}}$, and $\dot{K}$.

1. SALTS WITH A COMMON ANION.

Since anions electrically equivalent to the quantity of cations present should be found in the solution in order to avoid perplexing complications, and since by using one anion in equivalent quantity it seemed that we should be more likely to get a clear view of the action of the different cations, a series of solutions was made up in which $Ca(NO_3)_2$, $Mg(NO_3)_2$, and KNO_3 were mixed in all possible proportions. The result was a set of 36 cultures which when so arranged filled out the well-known triangular scheme of the physical chemists and plant physiologists.

Since the simple solutions occupying the vertices of the triangle and the mixtures of two salts which filled up the three sides fall into groups of experiments already considered, we shall consider here the fifteen "inside" mixtures in which all three salts were present. Moreover, since it seems hardly necessary to review all of these in detail, the most striking results may be briefly summarized (Table 8).

TABLE 8.—*Absorption by Lupinus albus seedlings from mixtures of two salts having a common anion* ($\bar{NO_3}$).[a]

Solutions.	Average maximum absorption of series. $N \times 10^{-6}$.	Percent.
KNO_3, $Ca(NO_3)_2$	44.1	31.5
$Mg(NO_3)_2$, $Ca(NO_3)_2$	53.3	38.1
KNO_3, $Mg(NO_3)_2$	22.2	15.8
Average from 2-salt (3-ion) solutions	39.9	28.5

[a] The total original concentration of each mixture was $140N \times 10^{-6}$.

In this and subsequent tables, percentages indicate the proportion of the original total number of ions that had been absorbed at the time of maximum absorption.

The favorable action of the Ca is clearly shown here.

The results seen in cultures containing three nitrate salts are shown in Table 9.

TABLE 9.—*Absorption by Lupinus albus seedlings from solutions containing three nitrates.*[a]

Solutions.	Maximum absorption. $N \times 10^{-6}$	Percent.
100 KNO_3, 20 $Ca(NO_3)_2$, 20 $Mg(NO_3)_2$	47.9	34.2
80 KNO_3, 40 $Ca(NO_3)_2$, 20 $Mg(NO_3)_2$	38.8	27.7
60 KNO_3, 60 $Ca(NO_3)_2$, 20 $Mg(NO_3)_2$	79.0	56.4
40 KNO_3, 80 $Ca(NO_3)_2$, 20 $Mg(NO_3)_2$	60.4	43.1
20 KNO_3, 100 $Ca(NO_3)_2$, 20 $Mg(NO_3)_2$	72.7	51.9
80 KNO_3, 20 $Ca(NO_3)_2$, 40 $Mg(NO_3)_2$	29.3	20.9
60 KNO_3, 40 $Ca(NO_3)_2$, 40 $Mg(NO_3)_2$	71.4	51.0
40 KNO_3, 60 $Ca(NO_3)_2$, 40 $Mg(NO_3)_2$	78.7	56.2
20 KNO_3, 80 $Ca(NO_3)_2$, 40 $Mg(NO_3)_2$	47.9	34.2
60 KNO_3, 20 $Ca(NO_3)_2$, 60 $Mg(NO_3)_2$	49.2	35.1
40 KNO_3, 40 $Ca(NO_3)_2$, 60 $Mg(NO_3)_2$	51.1	36.5
20 KNO_3, 60 $Ca(NO_3)_2$, 60 $Mg(NO_3)_2$	42.9	30.7
40 KNO_3, 20 $Ca(NO_3)_2$, 80 $Mg(NO_3)_2$	46.8	33.4
20 KNO_3, 40 $Ca(NO_3)_2$, 80 $Mg(NO_3)_2$	75.9	54.2
20 KNO_3, 20 $Ca(NO_3)_2$, 100 $Mg(NO_3)_2$	52.5	37.5
Average absorption in 3-salt (4-ion) solutions....	56.3	40.2
Average absorption in 2-salt (3-ion) solutions....	39.9	28.5

[a] The total original concentration of each solution was $140N \times 10^{-6}$.

From these results it seems clear that the increase in the number of cations from two to three alone serves to increase very materially the quantity of ions absorbed by these plants even when the only anion present is the $\bar{NO_3}$ ion.

2. SALTS WITH DIFFERENT ANIONS.

Similar three-salt mixtures were made up in which the three important nutrient cations $\overset{++}{Ca}$, $\overset{++}{Mg}$, and $\overset{+}{K}$, were electrically balanced by the three necessary nutrient anions, $\bar{NO_3}$, $\bar{\bar{SO_4}}$, and $\bar{\bar{\bar{PO_4}}}$. A similar triangular experiment was set up with a series of solutions having a constant total concentration of $140N \times 10^{-6}$.

Since new pairs of salts occur in the experiment each carrying a different anion, it seems worth while again to summarize the data for these mixtures. This is done in Table 10.

TABLE 10.—*Absorption by Lupinus albus seedlings from mixtures of two salts having different anions.*[a]

Solutions.	Average maximum absorption. $N \times 10^{-6}$	Percent.
KH_2PO_4, $Ca(NO_3)_2$	90.5	64.7
$MgSO_4$, $Ca(NO_3)_2$	85.1	60.8
$MgSO_4$, KH_2PO_4	44.4	31.7
Average absorption from 2-salt (4-ion) mixtures	73.3	52.4

[a] The original total concentration of each mixture is $140N \times 10^{-6}$.

By contrasting the absorption here seen with that given for 3-ion solutions (pairs of nitrates) in Table 8, the great increase due to the partial replacement of the $\bar{NO_3}$ ions with others in equivalent quantity, the importance of these newly introduced ions may be readily seen. Again, anions associated with leach in solutions of single salts when brought into a mixture are seen to bring with them a marked increase in absorption.

In Table 11 are shown the results obtained with mixtures of three salts yielding six of the nutrient ions required for the growth of higher green plants.

TABLE 11.—*Absorption by Lupinus albus seedlings from mixtures of three salts having different anions.*[a]

Solutions.	Maximum absorption. $N \times 10^{-6}$	Percent.
100 KH_2PO_4, 20 $Ca(NO_3)_2$, 20 $MgSO_4$	98.6	70.4
80 KH_2PO_4, 40 $Ca(NO_3)_2$, 20 $MgSO_4$	115.4	82.4
60 KH_2PO_4, 60 $Ca(NO_3)_2$, 20 $MgSO_4$	99.4	71.0
40 KH_2PO_4, 80 $Ca(NO_3)_2$, 20 $MgSO_4$	102.1	72.9
20 KH_2PO_4, 100 $Ca(NO_3)_2$, 20 $MgSO_4$	85.9	60.1
80 KH_2PO_4, 20 $Ca(NO_3)_2$, 40 $MgSO_4$	104.5	74.7
60 KH_2PO_4, 40 $Ca(NO_3)_2$, 40 $MgSO_4$	*122.3*	87.3
40 KH_2PO_4, 60 $Ca(NO_3)_2$, 40 $MgSO_4$	*120.9*	86.3
20 KH_2PO_4, 80 $Ca(NO_3)_2$, 40 $MgSO_4$	99.6	71.1
60 KH_2PO_4, 20 $Ca(NO_3)_2$, 60 $MgSO_4$	112.7	80.5
40 KH_2PO_4, 40 $Ca(NO_3)_2$, 60 $MgSO_4$	*123.1*	87.9
20 KH_2PO_4, 60 $Ca(NO_3)_2$, 60 $MgSO_4$	113.6	81.1
40 KH_2PO_4, 20 $Ca(NO_3)_2$, 80 $MgSO_4$	112.2	80.1
20 KH_2PO_4, 40 $Ca(NO_3)_2$, 80 $MgSO_4$	*121.6*	86.9
20 KH_2PO_4, 20 $Ca(NO_3)_2$, 100 $MgSO_4$	113.0	80.7
Average absorption from 3-salt (6-ion) solutions.	109.7	78.3

[a] The original total concentration of each mixture is $140N \times 10^{-6}$.

From the results above set forth, it appears that with the increase of the number of cations, the anion remaining common to them all, absorption is markedly increased, reaching in some all-nitrate mixtures over 50 percent of the total number of ions offered.

When the number of anions is increased by the introduction of the $\bar{\bar{\bar{PO_4}}}$ and $\bar{\bar{SO_4}}$ ions, absorption from solutions containing all six ions rises to an average of over 75 percent and in favorable cases reaches over 85 percent of the total number of ions present in the solution.

It appears that when six ions are present the proportions in which they occur may exert an important influence. The best results are seen when no single ion greatly predominates over the rest. However, within these limits a wide range of variation seems to accom-

pany almost equal efficiency. There seems to be little evidence to support the supposition that any very sharply marked balance must be observed. While this seems to be true when the solutions contain an increased number of ions, apparently more definite quantity relations have a greater significance when fewer ions are present.

Seedlings in Solutions Containing Three Salts and Iron.

As none of the mixtures already noted constitute a complete culture solution, experiments were undertaken by Dr. Grace A. Dunn, then of the Bureau of Plant Industry, working under the direction of the writer, designed to shed light on this feature of our problem.

The details of this work cannot be presented here, but the general result was clear in all cases. The presence of any of the iron salts commonly used in culture solutions did not in any marked way modify the rates of absorption previously found in the 3-salt solutions. It seems to be clear, therefore, that the use of iron to the seedling developing in darkness is not closely connected with the processes or structures decisive for absorption.

Conclusions.

The following conclusions may be drawn from the work outlined:

1. Pure water represents a partial ionic vacuum to roots of plants and tends to establish an equilibrium with the cell contents by the withdrawal of ions from the plant. This leads in some plants and animals to deep seated changes and to consequent injury.

2. This injurious action is not fully overcome by any one pair of ions (salt) tested, but is very largely overcome by salts yielding the Ca^{++} ion, to a very much less degree by those yielding the Mg^{++} ion, and but very sligthly or not at all by those carrying the K^{+} or Na^{+} ions.

3. The Ca salts most abundantly absorbed are $CaCl_2$, $CaCO_3$, and $Ca(NO_3)_2$. $CaSO_4$ also is absorbed in an approximately like degree by plants that are at home on sandy and acid lands, such as alsike clover, white lupine, and peanut. For hearty feeders that require rich soil and a higher lime content, the absorption from $CaSO_4$ solutions is much less than from solutions of the other Ca salts named. This difference is probably to be attributed to the influence of the anion. The way in which this influence is exerted is reserved for fuller discusison elsewhere.

4. The absorption of electrolytes is increased by the increase in the number of kinds of nutrient ions present in the solution. When accompanied by Ca^{++} ions, K^{+} ions, neglected when offered in simple

solutions, are absorbed. The $\overset{\cdot +}{Ca}$ ions establish conditions that secure the absorption of $\overset{+}{K}$ ions, or make them "physiologically available" and it seems that a similar, but less striking, action by $\dot{K}$ ions in securing absorption of $\overset{\cdot +}{Ca}$ ions exists. This type of effect is sometimes regarded as due to antagonistic action of ions. It seems to the writer to be due to the opposite type of action in which one ion helps another (synergism) and the increased efficiency coming from united action is greater than could be gained by the mere removal by one ion of an inhibitory action by another.[6] This is discussed more fully elsewhere.

5. As the variety of ions present in the solution is increased the importance of rather sharply marked proportional relations becomes ditsinctly less than in the simpler solutions. Essentially like absorption is found to prevail over a rather wide range of proportions provided no one ion greatly predominates over the rest or is present in too small quantity. The balance in the constituents of the soil solution seems not to be a delicate one for seedlings of plants studied.

6. Probably the most striking single chemical condition of the solution is the presence of a certain minimal quantity of $\overset{\cdot +}{Ca}$ ions. In *Lupinus albus* seedlings this seems to be a preliminary to the normal absorption of ions. Herein is to be seen one of the most important functions of calcium in plant nutrition. This seems to be the heart of the lime problem in agriculture. A certain minimal quantity of Ca ions seems to be necessary to secure the normal absorption of the other required ions present in the soil solution. Thru this relation, Ca ions make "physiologically available" the other nutrient materials contained in the soil solution.

In the special relation of the $\bar{S}O_4$ ion to absorption by seedlings of the different physiological types of higher plants, we seem to see a basis from which to approach a number of problems connected with the practical use of lime, limestone, and gypsum.

7. The basis for an understanding of the special service performed by the $\overset{\cdot +}{Ca}$ ion is doubtless to be sought in the physiology of the cell. Lime and limestone doubtless perform highly important work in the soil, but their chief utility does not seem to be there. They, with gypsum, furnish $\overset{\cdot +}{Ca}$ ions which play as important a part in plant nutrition in its strictest sense as $\dot{K}$ or $\overset{---}{PO_4}$ ions.

[6] True, R. H. Antagonism and balanced solutions. *In* Science, n. s., 41: 653–656. 1915.

NEED FOR LIME AS INDICATED BY RELATIVE TOXICITY OF ACID SOIL CONDITIONS TO DIFFERENT CROPS.[1]

BURT L. HARTWELL.[2]

The main purpose of this paper is to emphasize that the kind of plant to be grown determines, more than any other factor, the amount of lime to apply to the soil; in other words, it is concerning the lime requirement for an acre of a given crop plant that agronomists are called upon to advise. The term "lime requirement" is understood to refer to the amount of calcium carbonate, or material with equivalent alkalinity, required to counteract other than nutrient effects resulting from soil acidity, which may be detrimental to crop growth.

It is not to improve mechanical condition, to influence soil flora or fauna, nor to supply, directly or indirectly, strictly plant food ingredients that attention is given to so-called lime requirements. Only when the conditions resulting from these other factors are optimum can the relative lime requirements of different crops be determined by growing them upon an acid soil. Considerable confusion has arisen because mechanical or nutrient effects have not been eliminated when such comparisons have been made. It is the alkaline or neutralizing effect on the plant itself, or on the nutrient medium in which it grows, that it is desired to measure.

The interesting questions relating to just how the alkaline materials exert their effects, and to what extent calcium may be replaced by other alkaline elements, are largely avoided in this paper in order to observe more clearly the practical considerations connected with the lime requirements of crops.

Unless one has observed the comparative effect of lime on crops which are extremely different, the importance of this consideration is liable to receive less emphasis than it should. As examples of pairs of crops which are similar in many respects, yet very different in their lime requirements, mention may be made of watermelon and muskmelon, blackberries and raspberries, apple and quince, turnip

[1] Contribution 274 from the Agricultural Experiment Station of the Rhode Island State College. Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920.

[2] Director and agronomist, Rhode Island Agricultural Experiment Station.

and beet, beans and alfalfa, redtop and timothy, rye and barley. Under acid-soil conditions where no lime would be required for the first-mentioned of each pair, the requirement for the other may be large. Obviously, it serves no useful purpose, therefore, to make a statement of the lime requirement of a soil rather than of a crop. It seems hardly necessary to state that the measure of the acidity of the soil by any method which may be adopted is useful, but it must be considered in connection with the crop to be grown before intelligent suggestions for liming can be given.

Furthermore, the evidence is against the idea that diverse crops are affected differently by the acidity itself. For example, barley and rye are affected alike by a given amount of acid and yet they are influenced very differently by the same acid-soil conditions.

These facts should guard against over confidence in the value of a determination of soil acidity by any method. As an indication of a set of conditions, the determination is of value, but measurements should be made of those soil factors which are connected directly with the causes of the wide range in the lime requirements of crops.

That kind of plant whose growth is inhibited by acid-soil conditions may be suffering from a deficiency of one thing, such as calcium bicarbonate; from a toxic amount of another, such as aluminum; or from both.[3] It is scarcely reasonable to expect that an acidity determination can be correlated closely with such causal factors.

Excessive applications of acid phosphate to soils well supplied with available phosphorus, and yet so acid that certain crops could make no growth previously, have so changed the conditions that normal growth resulted. The acidity, however, had been much increased, at least temporarily, by the acid phosphate.

Greater attention needs to be given to the relations between the nature of the metabolism resulting in the proximate constituents of a given crop and the absorption, by the latter, of materials from the soil. Altho determinations of certain of these materials are legion, comparatively little attention has been given to a consideration of the entire amount absorbed per acre. The acre basis is emphasized because there is such a wide difference in the average yields of different kinds of crops in any locality that the percentage relations are quite deceiving. It needs to be kept in mind that we have to deal with the lime requirement of a crop per acre, and not per hundred or per ton.

[3] There is an important distinction which should be appreciated between the toxicity of aluminum itself, and of the acidity resulting from the hydrolysis of its salts. Those who recognized the latter did not thereby discover a reason for the great range in the lime requirements of different crops.

Concerning many of the ordinary ash analyses it is well understood that a large part of the chlorin and sulfur, as well as all of the nitrogen, disappeared during the incineration; and yet in nonlegumes these ingredients all came from the soil solution, and preferably enter the plant in combination as acidic elements. It is of the utmost importance to know the relation between the total equivalent of acid and of alkaline radicals; that is, to have a statement of the net alkalinity or acidity, as the case may be, of the materials absorbed from an acre by our average crops.

In view of the fact that these materials come from the most active part of the soil, a profound difference is, under critical conditions, brought about in that particular part by the removal of one instead of another of two crops, having, for example, a net difference in the reaction of the absorbed materials equivalent to a thousand pounds of calcium carbonate. It is not surprising that two such crops should have different lime requirements, whether because of their specific needs or because of an effect on the soil solution by which the toxicity ot certain soil ingredients is inhibited or enhanced, as the case may be.

Inasmuch as different crops do alter the soil in such a way that the lime requirement of a given crop grown subsequently is distinctly modified, one would hesitate to grow, successively, two crops with high lime requirement, without positive assurance that the liming was sufficient to satisfy the needs of both. On acid soils this effect of different crops on a following crop may be very marked, and the succession of crops in a rotation under such a condition is an extremely important matter regardless of the supply of nutrients.

Frequently it is inadvisable to satisfy fully the lime requirements of a crop because of the development of undesirable associates, for example, weeds in a lawn. By selecting a lawn grass which is not very sensitive to acid-soil conditions, a host of weeds may be warded off by withholding lime, an end which is fully justified even tho the grass itself does not make the most rapid growth.

A digression seems warranted here from a consideration of undesirable conditions accompanying a high degree of soil acidity to those which frequently arise when the soil has been neutralized by liming. Too many agronomists are stating that soil should be made "neutral or slightly alkaline." Doubtless they have in mind the productivity of calcareous soils and the nontoxicity of calcium carbonate.

It is no wonder that Dame Nature balks on occasions when mere man attempts to transform a naturally acid soil into a calcareous one. Nor is it sound reasoning to overlook the potent changes which take

place in the chemistry of the soil in passing from an acid to an alkaline reaction. A vision is needed of a test tube containing a solution of calcium, iron, and phosphorus and what happens when the neutral point is reached by the addition of an alkali.

Observations of chlorosis, or abnormal green, as well as of growth inhibition of crops with low lime requirement, resulting from over liming with any form of lime, are sufficiently numerous to suggest that as soon as a campaign for the use of lime has become successful in any quarter, a second campaign against the over use of lime in that same quarter should be launched at once. Otherwise, the same old lime "saws" will be found to have as sharp teeth as formerly.

It is hoped that our commercial lime interests will give heed, for we are all too much impressed with the value of liming to enjoy the contemplation of anything but the continued economic success of the operation from the farmer's standpoint. Only on such a basis can the lime industry itself enjoy permanent prosperity. Temporary profits which lead to later paralysis must be avoided.

It will take more than the combined influence of agronomists to provide for adequate chemical and physiological study of the intricate relations of the soil and crop. Business interests must be awakened to the necessity of retaining in research those with the ability to work for the earliest possible solution of practical difficulties.

If the usual practice of liming only once in every few years shall continue, the weather conditions of a single year will fortunately have less influence than they do on annual operations. Greater success may be attained therefore in determining lime requirements than has rewarded the chemist in his search for methods of determining for the farmer the nitrogen, phosphorus, and potassium requirements for a coming season. Here again the agronomist has frequently been guilty of fixing attention on the needs of the soil rather than on the needs of the individual crop, and has used methods for determining phosphorus activity, for example, without regard to such facts as that carrots can secure their entire needs for phosphorus under conditions where turnips can scarcely get a start.

Doubtless we should know the acidity of a soil as measured by the concentration of the hydrogen ions and by the concentration of similar factors; the amount of calcium bicarbonate which is generated; the amount of active aluminum, not merely the acidity resulting from the hydrolysis of its salts; and much other information about the soil. It should never be overlooked, however, that such information must be correlated with the response of the individual crop. A PH of 5,

an acidity in terms of calcium carbonate per acre equal to 4,000 pounds by the Veitch method, 5,000 pounds by the Jones method, or 1,000 pounds by the Hopkins method, an activity of aluminum represented by as high as 0.005 percent, or one of calcium bicarbonate by as low as 0.001 percent, must each or all be interpretable in terms of the amount of lime required by an acre of beets, for example, if they are to be of immediate service to practical agriculture.

Who is prepared to make these interpretations? Evidently the Association of Official Agricultural Chemists has learned conservatism from experience, for in its latest revision of methods it ventures to outline for service in this connection, tentatively, only a qualitative test for soil reaction by the use of litmus paper.

A working plan would be: (1) Divide those crops which need lime into grades 1, 2, and 3, representing low, medium, and high lime requirements as determined by actual field tests with the crops. (2) State specifically for each determination or method believed to be useful in connection with the study of the soil, the ranges which are supposed to indicate low, medium, and high requirements. (3) Designate a small, medium, and large application of lime.

Such directions as the following might then be useful: A low lime-requirement crop to be grown on soil whose chemical reactions indicate low requirement would need no lime; if the soil indicates medium requirement, the small application of lime would suffice; if the soil indicates high requirements, the medium application of lime would be enough. For a medium lime-requirement crop the application of lime should be small, medium, or large, respectively, depending directly upon whether the chemical tests of the soil indicate low, medium, or high requirements. For high lime-requirement crops the medium quantity of lime should be added, even when the chemical tests of the soil indicate a low requirement; the large quantity when the tests of the soil indicate medium requirements; and when the tests of the soil as well as the kind of crop indicate high requirement, a quantity of lime even in excess of the standard adopted as a large amount may prove profitable.

A tentative classification of crops which may need liming has been made already into three grades. Furthermore, it has been suggested for southern New England that the small, medium, and large applications be equivalent respectively to about 1,000, 2,000, and 3,000 pounds per acre of calcium carbonate in finely ground limestone. If, in addition, the soil chemists in case of all promising tests will agree upon the range of each of three magnitudes, indicating respectively low, medium, and high requirements, distinct progress has been made.

LIMING IN ITS RELATION TO INJURIOUS INORGANIC COMPOUNDS IN THE SOIL.[1]

S. D. CONNER.[2]

Lime in its various forms is known to affect soils in a great many ways, both chemical and physical. This paper is confined to a discussion of the action of lime, both calcium and magnesian, in various forms in decreasing the injurious action of inorganic compounds which may be in the soil. There are three ways in which lime is known to lessen the harmful action of injurious compounds.

It will neutralize acids in the soil and in this way decrease the hydrogen ion concentration.

It will precipitate many soluble injurious salts.

It in some cases exerts a so-called and not very well understood antagonistic action towards soluble injurious compounds which may or may not remain soluble.

THE REDUCTION OF ACIDITY.

Several forms of lime reduce acidity more or less. Together with the corresponding magnesium compounds, calcium oxid, calcium hydroxid, calcium carbonate, calcium silicate, and, to a slight extent, calcium phosphate exert such an action. This reduction of acidity is beneficial to most agricultural crops. It is now rather widely known, however, that it is possible to use too much lime for maximum results. There is a certain optimum range of H-ion concentration for the soil solution at which crops do best. This varies with different crops and in many instances is slightly on the acid side of neutrality.

THE PRECIPITATION OF SOLUBLE SALTS.

Liming is the most common and cheapest method of precipitating soluble injurious compounds in the soil. The soluble injurious inorganic salts that are found in acid soils are the ones which are precipitated by lime. Among such salts may be mentioned aluminum, iron, manganese, zinc, and boron. Of all these, aluminum is by far

[1] Contribution from the Purdue University Agricultural Experiment Station, LaFayette, Ind. Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920.

[2] Soil chemist, Purdue University Agricultural Experiment Station.

the most prevalent. It exists in greater or less quantities in all acid soils, depending upon the degree of acidity and the physical character of the soil. Soluble salts of aluminum have been known for some time to be present in acid soils and to be injurious to plants. Abbott, Conner, and Smalley (1)[3] in 1913 reported experiments upon an unproductive acid soil which contained relatively large amounts of soluble aluminum salts. It was shown that the aluminum salts were the principal toxic agents. Liming precipitated the aluminum and rendered the soil more productive. Ruprecht (16) in 1915 reported the presence of soluble salts of aluminum and iron in acid soil at the Massachusetts station. Kratzman (11) in 1914 reported that aluminum salts exerted a general poisoning effect upon some plants. Miyake's (15) results in 1916 indicated, and Hartwell and Pember's (9) in 1918 quite definitely proved that to a certain extent on some crops the aluminum ion was toxic rather than the H ion which accompanies it. Just recently Mirasol (14), working at the University of Illinois, has obtained results which also indicate that aluminum salts are always present in acid soils and are probably the dominant factor in affecting plant growth in such soils.

Iron is seldom found in excessive amounts in soluble form in soils. The only forms of iron in the soil known to be injurious to plants are the ferrous salts. Ferrous iron salts are only found in poorly aerated acid soils. Altho liming would correct soil acidity, it would not render a waterlogged soil productive to ordinary crops. Hoffer and Carr in unpublished results obtained at the Indiana station working in cooperation with the Bureau of Plant Industry have found that aluminum and ferrous iron salts exert a distinctly injurious effect when introduced into a growing corn stalk. This poisoning does not occur with acids of the same strength. They found a similar type of injury in corn growing in acid soils.

Manganese is much more soluble in an acid soil than in a neutral one. Skinner and Reid (18) reported experiments in 1916 showing that the toxicity of manganese is largely prevented by liming. In soils containing excessively large amounts of manganese, however, the presence of plenty of lime does not prevent manganese injury (10). Manganese as well as ferrous iron is increased in solubility when acid soils are waterlogged (3), and would no doubt tend to exert a harmful influence in the absence of drainage and liming. Funchess' (7) latest work shows that soluble manganese salts are not so harmful in certain Alabama soils as they were at first reported to be.

[3] Reference by number is to "Literature cited," p. 123.

Sometimes less common inorganic compounds are introduced in soils in harmful amounts. In the neighborhood of smelters, sulfuric acid, zinc, or arsenic quite often partially or entirely destroy vegetation. Such injury can be to a very great extent prevented by heavy liming. Experiments have shown that zinc is not soluble in limed soils and not nearly so injurious (4).

Boron has been added to soil in injurious quantities in some potash salts and possibly in some of the nitrates used for fertilizers. The use of or the presence of enough lime to render the soil neutral will allow the borax to form insoluble combinations in the soil and decrease the damage. This would explain why borax injury was greater on acid than on neutral soils (5).

Antagonistic Action of Calcium.

Under certain conditions magnesium compounds may exist in soils in harmful quantities. Calcium compounds are known to exert a more or less antagonistic action and will under some conditions of soils and crops neutralize the effect of magnesium poisoning.

On an acid black loamy sand in a pot test at the Indiana station, clover and wheat failed entirely with an application of 4 tons of calcium sulfate per 2,000,000 pounds of soil, likewise with a 12-ton application of magnesite. Red beets produced no crop with 4 tons of calcium sulfate and only 0.5 gram per pot with 12 tons magnesite, but in a pot with a combination of 12 tons magnesite plus 4 tons calcium sulfate 109 grams of beets were grown, while a 4-ton application of hydrated lime grew only 66 grams of beets. The combination of magnesite and calcium sulfate failed to produce any crop of corn, buckwheat, or oats. Lime sulfate is often used to lessen the injury of sodium carbonate (black alkali). LeClerc and Breazeale (12) have recently shown that lime either in the form of oxid or sulfate will lessen the toxic action of excessive amounts of sodium salts on wheat seedlings.

Experimental Evidence.

In view of the fact that quite large quantities of soluble aluminum salts had been found in Indiana acid soils and that the aluminum salts had been shown to be toxic (1), water culture tests were started for the purpose of throwing more light upon the question of whether the aluminum ion or the H ion was the toxic agent. The details of the complete investigation which was conducted by Mr. O. H. Sears and myself will be published in a separate article. Barley and rye

seedlings were grown in 2,100-c.c. wide-mouth glass bottles. Shive's (17) 3-salt stock solutions containing the following salts per 2 liters were prepared:

KH_2PO_4	22.304 grams.
$MgSO_4$	6.720 grams.
$Ca(NO_3)_2$	24.270 grams.

The nutrient solution contained 20 c.c. of each stock solution per 1,000 c.c. of aerated distilled water, making a concentration of approximately 0.2 atmosphere osmotic pressure. Two c.c. of dilute ferric citrate were added to each bottle, and 60 c.c. lime water was also added as the nutrient was slightly acid. Four strengths of sulfuric acid and four strengths of aluminum sulfate were used. Series were carried in duplicate and continued four weeks. The total plants were dried and weighed.

TABLE 1.—*Relative weights of barley and rye grown in water cultures of Shive's nutrient solution.*

No.	Treatment.	C.c. $\frac{N}{5}$.	PH.	Relative weights.	
				Barley.	Rye.
1	H_2SO_4	6.0	3.6	30.5	43
2	H_2SO_4	3.7	4.3	59.1	31
3	H_2SO_4	2.7	5.0	53.8	72
4	H_2SO_4	2.2	5.7	93.9	103
5	$Al_2(SO_4)_3$	10.0	3.9	33.8	43
6	$Al_2(SO_4)_3$	6.0	4.3	63.7	71
7	$Al_2(SO_4)_3$	4.2	5.0	93.4	75
8	$Al_2(SO_4)_3$	2.9	5.7	96.1	84
9	Check	—	6.3	100.0	100

Hydrogen-ion determinations were made by the colorimetric method. Solutions were changed daily so there would be no change in H-ion concentration. Weights given are relative to 100 for the checks. The results of this test and of several preliminary tests run at previous dates indicated that the toxicity of aluminum sulfate was due entirely to the H ion and not to the aluminum. However, in the cultures containing aluminum sulfate, there was quite a distinct precipitate, indicating that the aluminum had been thrown out of solution probably by phosphorus. The Shive's (17) nutrient used contained 26 times as much phosphorus as Hartwell and Pember's (9) nutrient. The following amounts of different elements were contained in the two nutrient solutions used.

TABLE 2.—*Grams of various elements per 1,000 c.c. of nutrient solution.*

	Shive's.	Hartwell and Pember's.
P	0.055	0.002
N	.042	.070
K	.067	.030
Ca	.060	.053
Mg	.013	.020
S	.018	.026

To throw more light upon this point a series of water cultures were run with the nutrient prepared according to Hartwell and Pember. The results are shown in Table 3.

TABLE 3.—*Relative weights of barley and rye grown in water cultures of Hartwell and Pember's nutrient solution.*

No.	Treatment.	C.c. $\frac{N}{5}$.	PH.	Relative weights. Barley.	Rye.
1	H_2SO_4	2.00	3.9	73	65
2	H_2SO_4	1.00	4.2	93	95
3	H_2SO_4	.50	5.0	90	90
4	H_2SO_4	.25	5.7	101	95
5	$Al_2(SO_4)_3$	5.00	3.9	47	55
6	$Al_2(SO_4)_3$	1.30	4.2	68	65
7	$Al_2(SO_4)_3$	.75	5.0	91	80
8	$Al_2(SO_4)_3$	.50	5.7	121	90
9	Check	—	6.3	100	100

The results from the test with Hartwell and Pember's nutrient which is very low in phosphorus and which did not precipitate the aluminum indicate that not only is the H ion toxic but that the aluminum itself is toxic especially to barley in the more acid concentrations. A comparison of the results from tests with the two nutrient solutions indicate that phosphorus is to a certain extent an antidote and will decrease the harmful action of aluminum salts. When 2,100 c.c. of Hartwell and Pember's nutrient is used and changed daily, the check and weaker acid treatments show no lack of phosphorus.

POT TESTS.

In a series of pot tests on an acid black loamy sand soil started in February, 1918, several different materials were applied, all at the rate of 4 tons per 2,000,000 pounds of soil. All pots had a uniform treatment of 31 lbs. N, 160 lbs. P_2O_5, and 108 lbs. K_2O per acre, in the form of diammonium phosphate and dipotassium phosphate. Red beets were harvested May, 1918; popcorn in September, 1918; buckwheat, March, 1919; and oats, October 1, 1919. The results are given in Table 4.

TABLE 4.—*Grams of various crops per pot produced in pots of acid black sand, with acidity at end of test.*

Pot No.	Treatment.	Beets.	Corn.	Buckwheat.	Oats.	PH.	Acidity. Hopkins.	Acidity. Jones.
3	None	0	0	[a]0	[a].05	4.2	2,500	12,500
18	H_3PO_4	.5	5.0	[a].5	[a].50	4.1	3,080	13,500
19	$CaH_4(PO_4)_2$	160.0	48.0	[a].5	[a].20	4.2	1,800	12,500
20	Acid phosphate	.5	0	[a].5	[a].50	4.1	2,700	12,500
21	$Ca_3(PO_4)_2$	271.0	16.0	[a].6	[a].60	4.4	1,000	9,500
22	$Ca(OH)_2$	240.0	.5	29.5	3.80	6.0	160	6,500
23	Ca_2SiO_4	285.0	44.0	14.5	9.00	6.0	340	7,500
24	H_2SiO_3	5.0	0	[a].1	[a].20	4.2	2,840	12,000

[a] Yields probably depressed by zinc salts dissolved from galvanized pots.

Figure 2 shows the relative growth of red beets, popcorn, and Silverhull buckwheat with various tratments in acid black sand soil.

The results obtained in this series of pot tests can be explained on the basis of aluminum toxicity. This is the same soil reported in Purdue Univ. Agr. Expt. Sta. Bul. No. 170, and in which large amounts of soluble aluminum salts were found. The determinations of acidity and of the H-ion concentration of soil from each pot shows that the crops were not in proportion to the H ions or acidity by other methods. The basic fertilizer furnished ample supplies of plant food. The obvious explanation lies in the fact that aluminum salts are toxic and that aluminum phosphates and aluminum silicates are much more insoluble than aluminum hydroxid. In pots 19 and 21 the phosphates had reduced the aluminum salts but had left a fairly high degree of acidity, yet the yields of both beets and corn were good. When corn was grown in pot 18 with the highest acidity of all, a 4-ton application of 85 percent liquid phosphoric acid produced more corn than pot 22 with the least acidity. While excessive acidity is injurious to corn, it would seem that in certain ranges the aluminum ion is even more toxic than the H ion. The reason buckwheat and oats failed to make growth with the phosphates is probably due to the toxic action of zinc which was dissolved in the soil from the galvanized pots (4). It is interesting to note that with the first, second, and fourth crops grown, calcium silicate produced greater crops than calcium hydroxid with practically the same soil acidity. This is also in accord with the theory of aluminum toxicity, aluminum silicate as well as aluminum phosphate being much less soluble than aluminum hydroxid at the same H-ion concentration. This might be the reason why calcium silicate has sometimes given better results than lime in soil tests by others (6, 13). The reason 4 tons per acre of acid phosphate did not produce as good results as 4 tons of monocalcium phosphate is

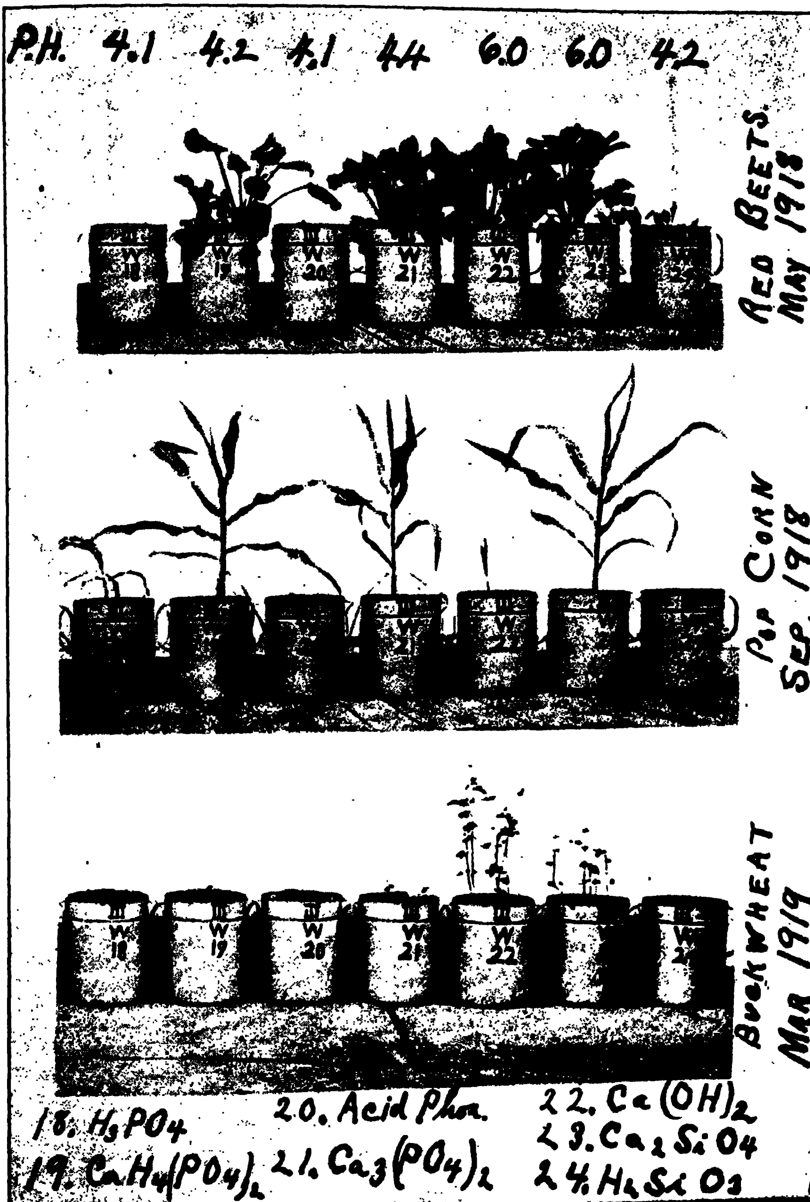


FIG. 2. Crowth of red beets, popcorn, and buckwheat on acid black sand with lime, phosphates, and silicates.

because there was not so much phosphoric acid applied. In a later *pot test on this soil a 15-ton per acre application of acid phosphate produced good results on corn, while a 5-ton application of calcium carbonate failed entirely.*

LABORATORY TESTS.

To determine the relative solubility of aluminum hydroxid and aluminum phosphate at different H-ion concentrations, a series of precipitations were made. To 5 c.c. portions of fifth-normal aluminum nitrate were added varying amounts of half-normal sodium hydroxid. The H-ion concentration and the weight of precipitate were determined. In a like manner 2 c.c. N/2 $KH_2(PO_4)$ was added to 5 c.c. N/5 $Al(NO_3)_3$ and precipitated at different H-ion concentrations and the precipitates weighed. Table 5 gives the results of these tests.

TABLE 5.—*Relative solubility of Al_2O_3 and $AlPO_4$ at different H-ion concentrations.*

PH.	$\frac{N}{2}$ NaOH.	Al_2O_3.	$\frac{N}{2}$ NaOH.	$AlPO_4$.
	Cubic centimeters.	*Grams.*	*Cubic centimeters.*	*Grams.*
3.3	—	—	0	0
3.5	—	—	.50	.0092
3.8	—	—	1.00	.0356
3.9	0	0	1.20	.0363
4.0	—	—	1.30	.0364
4.3	1.20	.0009	1.35	.0344
4.8	1.40	.0012	1.40	.0332
5.0	1.50	.0014	—	—
5.3	1.60	.0014	—	—
5.4	—	—	1.45	.0332
6.0	1.65	.0140	1.50	.0326
6.3	1.70	.0168	—	—
6.4	—	—	1.60	.0325
6.5	—	—	1.80	.0311
6.6	1.80	.0166	—	—

The results shown in Table 5 indicate that it is possible to precipitate soluble aluminum salts in a soil with phosphates at P_H 3.9 more completely than Al_2O_3 can be precipitated with lime at P_H 6.0. This would explain why corn, which is sensitive to the aluminum ion, grew better at P_H 4.2 with 4 tons monocalcium phosphate than it did at P_H 6.0 with 4 tons hydrated lime. These Al_2O_3 solubilities are in accord with the results obtained by Blum (2).

FIELD TESTS.

In 1920 a series of field tests were started on a new experiment field at Wanatah. Limestone was used at the uniform rate of 4 tons

per acre on a series of plats. Other treatments were given as shown in Table 6. Oats, corn, and soybean-millet hay have been harvested.

TABLE 6.—*Yields of oats, corn, and soybean-millet hay on plats variously treated on Wanatah field, 1920.*

Treatment per acre					Yield per acre.		
Limestone.	KCl.	Acid phosphate.	Rock phosphate.	Calcium silicate.	Oats.	Hay.	Corn.
Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*
0.....	0	0	0	0	[a]34	[a]1,080	[a]1.8
8,000.....	0	0	0	0	[b]40	[b]1,557	[b]5.4
8,000.....	100	0	0	0	36	1,697	5.6
8,000.....	0	300	0	0	45	1,580	8.5
8,000.....	100	300	0	0	45	1,842	11.5
8,000.....	100	300	0	2,000	57	2,529	19.2
8,000.....	100	1,000	0	0	62	3,787	17.9
8,000.....	100	——	2,000	0	41	1,997	10.3

[a] The untreated yield is an average of three plats.
[b] The lime alone is an average yield of eight plats.

Where 300 pounds acid phosphate, an amount sufficient to furnish phosphorus for all plant-food needs of the crops, was applied in addition to lime, maximum yields were not obtained; but where 1,000 pounds of acid phosphate was applied the yield of oats was increased 17 bushels per acre, corn about 6 bushels per acre, and the soybean-millet hay yield was doubled over the normal acid phosphate yield. Likewise the 1-ton application of calcium silicate gave an increase of 12 bushels of oats, 7 bushels of corn, and 700 pounds of hay over the lime, potash, and phosphate treatment. These results also indicate that both the heavy phosphate and the calcium silicate treatments had exerted an effect other than furnishing plant food. This effect can be explained on the basis of more complete precipitation of toxic aluminum salts.

We have never been able to grow a normal corn crop on this soil even with limestone applications up to 14 tons per acre until after a lapse of three years. It is quite possible that the aluminum hydroxid remains toxic until it is gradually fixed as a single or double silicate or phosphate or in a more insoluble hydroxid. At any rate, plenty of available phosphate or silicate hastens the improvement in fertility and crop-producing power.

It is a widely observed fact that acid soils almost universally respond to phosphate fertilizers. It is quite probable that at least a part of this response is due to the action of phosphates in reducing soluble aluminum salts in acid soils. The Rothamsted results show

that barley is a crop that responds to phosphate more than almost any other crop. The Rhode Island results as well as the Indiana tests show that barley is particularly sensitive to aluminum toxicity.

In water cultures we have found that young seedlings which had been stunned by aluminum salts were more or less permanently injured and were seemingly unable to recover when placed in normal nutrient solutions. In 1847, Sir John Lawes (8) wrote, "Whether or not superphosphate of lime owes much of its effect to its chemical actions in the soil, it is certainly true that it causes a much enchanced development of the underground collective apparatus of the plant, especially of lateral and fibrous roots." Many instances have been noted where a small amount of acid phosphate applied in the drill has produced increases much greater than the amount of phosphorus as a plant food would seem to warrant. This effect may well be due partly to the protective action of phosphate on the young seedling.

All the evidence at hand shows conclusively that lime is a powerful agent in improving the chemical condition of the soil and in correcting the toxic influence of injurious inorganic compounds contained therein. It is also evident that lime alone is not always sufficient but that phosphorus is generally needed to supplement lime in the improvement of acid soils.

Summary.

1. Lime may act on injurious inorganic compounds in the soil in three ways:

(*a*) It neutralizes soil acidity by decreasing the H-ion concentration.

(*b*) It precipitates most injurious soluble salts which are found in acid soils.

(*c*) It, to a certain extent, acts in an antagonistic manner towards excessive soluble salts which may not be precipitated.

2. Aluminum, iron, manganese, boron, and zinc in soluble forms are harmful but they may be rendered less soluble and less injurious by lime.

3. Much of the harmful acidity of acid soils is due to the presence of soluble aluminum salts.

4. Aluminum toxicity is at least partly due to the aluminum ion. This action is more pronounced with barley than with rye.

5. The presence of abundant phosphates in the nutrient prevents aluminum injury, by precipitation.

6. Red beets were grown in an acid soil with the addition of monocalcium and tricalcium phosphate, calcium hydroxid, and dicalcium silicate.

7. Popcorn grew with all these materials except calcium hydroxid.

8. The growth of beets and corn was not in proportion to the H-ion concentration or soil acidity.

9. At P_H 3.9 aluminum is more completely precipitated as a phosphate than it is at P_H 6.0 as a hydroxid.

10. Aluminum is much more insoluble as a silicate than it is at the same acidity as a hydroxid.

11. In field plats, lime alone did not produce optimum crops on an acid black sand. Half a ton of acid phosphate or 1 ton of dicalcium silicate per acre produced good crops on limed land.

12. On sandy and peaty acid soils low in active silica, liming should be supplemented by available phosphates to correct aluminum toxicity.

13. The more active forms of silicates to a certain extent aid in precipitating aluminum salts.

LITERATURE CITED.

1. ABBOTT, J. B., CONNER, S. D., and SMALLEY, H. R. Soil acidity, nitrification, and the toxicity of soluble salts of aluminum. Ind. Agr. Expt. Sta. Bul. 170. 1913.
2. BLUM, WM. The determination of aluminum as oxide. *In* Jour. Amer. Chem. Soc., v. 38, no. 7, p. 1282–1297. 1916.
3. CONNER, S. D. Soil acidity as affected by moisture conditions of the soil. *In* Jour. Agr. Research, v. 15, no. 6, p. 321–329. 1918.
4. ——. The effect of zinc in soil tests with zinc and galvanized iron pots. *In* Jour. Amer. Soc. Agron., v. 12, no. 2, p. 61–64. 1920.
5. ——, and FERGUS, E. N. Borax in fertilizers. Ind. Agr. Expt. Sta. Bul. 239. 1920.
6. COWLES, A. H. Calcium silicates as fertilizers. *In* Metallurg. and Chem. Eng., v. 17, p. 664, 665. 1917.
7. FUNCHESS, M. J. Acid soils and the toxicity of manganese. *In* Soil Sci., v. 8, no. 1, p. 69. 1919.
8. HALL, A. D. Fertilizers and Manures, p. 139 (quotes Sir John Lawes). Dutton & Co., New York. 1909.
9. HARTWELL, B. L., and PEMBER, F. R. The presence of aluminum as a reason for the difference in the effect of so-called acid soil on barley and rye. *In* Soil Sci., v. 6, no. 4, p. 259–277. 1918.
10. KELLEY, W. P. The influence of manganese on the growth of pineapples. Hawaii Agr. Expt. Sta. Press. Bul. 23. 1909.
11. KRATZMAN, E. Action of aluminum salts on plants. *In* Chem. Ztg., v. 38, p. 1040. 1914.
12. LECLERC, J. A., and BREAZEALE, J. F. Effect of lime upon the sodium-chlorid tolerance of wheat seedlings. *In* Jour. Agr. Research, v. 18, no. 7, p. 347–356. 1920.
13. MACINTIRE, W. H., and WILLIS, L. G. Comparison of silicates and carbonates as sources of lime and magnesia for plants. *In* Jour. Indus. and Eng. Chem., v. 6, no. 12, p. 1005–1008. 1914.
14. MIRASOL, J. J. Aluminum as a factor in soil acidity. *In* Soil Sci., v. 10, no. 3, p. 153–193. 1920.

15. MIYAKE, K. The toxic action of soluble aluminum salts upon the growth of the rice plant. *In* Jour. Biol. Chem., v. 25, no. 1, p. 23–28. 1916.
16. RUPRECHT, R. W. Toxic effect of iron and aluminum salts on clover seedlings. Mass. Agr. Expt. Sta. Bul. 161. 1915.
17. SHIVE, J. W. A study of physiological balance in nutrient media. *In* Physiol. Researches, v. 1, no. 7, p. 327–397. 1915.
18. SKINNER, J. J., and REID, F. R. The action of manganese under acid and neutral soil conditions. U. S. Dept. Agr. Bul. 441. 1916.

THE EFFECT OF LIMING ON THE COMPOSITION OF THE DRAINAGE WATER OF SOILS.[1]

T. L. LYON.[2]

Not many experiments have been conducted in which a study of the effect of liming on the composition of the drainage water of soils has been a feature. Applications of potash salts, both muriate and sulfate, have more commonly been made and these have usually resulted in finding that such applications increase the removal of calcium and magnesium in the drainage water. As calcium is a cheaper soil amendment than potassium it is worth while to know whether liming a soil will liberate potassium and also what other phenomena may be noted by means of the drainage water as the result of applications of lime. This may also give some information as to why liming is so often beneficial to soils and may help to clear up the mystery which seems to surround the condition commonly called "soil acidity." As yet, however, the study of drainage water has not progressed far enough to throw much light on the "acidity" problem.

In reviewing the literature on the subject the various papers will be taken up in chronological order unless there is some special reason for doing otherwise. Only those investigations will be reviewed in which calcium or magnesium compounds have been applied to the soil. Applications of potassium salts will not be included. The term liming will be used to mean the application of calcium compounds only. When applications of magnesium compounds are considered they are not included under liming but are referred to as the specific substance. This is also true of applications of dolomite.

[1] Read by title in the absence of the author at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920. Contributions from the Department of Soil Technology, Cornell University Agricultural Experiment Station, Ithaca, N. Y.

[2] Professor of soil technology in the College of Agriculture of Cornell University.

One of the few European experiments with lysimeters in which lime was applied to soils was conducted by Tacke, Immendorff, and Minssen (8),[3] who used moor soil in small containers. Applications of lime did not increase the quantity of calcium in the drainage water. Only after repeated applications of lime was there any apparent liberation of potassium by the soil. Moderate applications of lime did not have much effect on the quantity of nitrates that appeared in the drainage water. Larger applications of lime resulted in increased nitrification in the soils poor in calcium but had little influence on soils rich in calcium.

Eckart (2) conducted experiments with lysimeters, each holding 250 pounds of soil which was sandy but high in calcium. In a series of these vessels 100 grams of lime per 100 pounds of dry soil were applied in different compounds. Burnt lime, ground coral, and gypsum were used. Determinations of nitrate nitrogen in the drainage water showed that there was no increase of nitrification resulting from the use of burnt lime and possibly a slight decrease. Ground coral increased nitrification quite markedly while gypsum depressed it strongly. In the same experiment gypsum increased the quantity of potash in the drainage water at the rate of 198 pounds per acre, but burnt lime and ground coral did not cause any significant increase in the solubility of the potash. Gypsum also effected an increased removal of calcium, but burnt lime and ground coral did not.

Peck (7) also conducted lysimeter experiments at the Sugar Planters' Experiment Station in Hawaii, altho he did not use the same containers as did Eckart. Peck's vessels were 8 inches in diameter and 2 feet in depth. Two soils were used, both of which were sandy loams. One, an upland loam, was acid to litmus; the other from lowland, was alkaline to litmus. To one set of vessels containing the acid soil lime was applied in the forms of oxid, carbonate, and sulfate, a sufficient quantity of each being used to supply calcium oxid at the rate of 1 ton to the acre foot. To the alkaline soil calcium oxid was applied. The soils were kept free of vegetation. The vessels were irrigated with distilled water at intervals of two weeks, and ten irrigations were given, amounting in all to about 23 vertical inches.

All three forms of lime increased nitrification in the acid soil, but with the alkaline soil the only form of calcium applied, the oxid, depressed nitrification to a very great degree. In the acid soil all three forms of lime increased the quantities of calcium and potassium in

[3] Reference is to "Literature cited," p. 130.

the drainage water, but in the alkaline soil calcium oxid caused very little difference in these constituents.

Both Eckart and Peck are inclined to attribute the depressing effect of burnt lime on nitrification to an undue alkaline reaction of the soil caused by the application. The depressing effect was not noted in the acid soil used by Peck.

Broughton (1) treated three soils, a sand, a clay, and a loam, with commercial lime in the forms of burnt lime (oxid), ground limestone, ground oyster shells, phosphate of lime, and gypsum. He also used a pure calcium oxid. The soils were placed in large stoneware jars glazed inside and out and having an outlet on the side near the bottom. A set of each was placed in the greenhouse and another set outside, all being allowed to stand for one year. The various forms of lime were applied in equal quantites of calcium at the rate of 4,000 pounds of CaO per acre and mixed with the upper 6 inches of soil. Water was poured on the surface of the soil in the greenhouse pots in amounts and at intervals corresponding to the average amount and distribution of rainfall for a series of years. The outside pots received the natural rainfall. The drainage was collected for one year, measured, and calcium determined.

The clay soil lost much less calcium in the drainage water than did either the sand or loam, between which soils there was little difference. As there was no untreated soil it is not apparent that the application of lime increased the removal of calcium.

Of the various forms of lime, gypsum caused by far the greatest loss of calcium. There was appreciably more calcium removed from the soils to which limestone was applied than from those to which burnt lime was added and this was true with each of the three soils. Rock phosphate treated soils gave less calcium in the leachings than did any of the forms of lime used in the experiment.

MacIntire, Willis and Holding (5) analyzed the drainage water from a mellow sandy loam soil contained in a number of galvanized iron cylinders with drainage pipe at the bottom. About half of these cylinders held 1 foot of surface soil and in the other half a 1-foot layer of subsoil was placed beneath the surface layer. Duplicate vessels were treated with calcium oxid and carbonate in chemically equivalent quantities of calcium and with magnesium carbonate, the treatments in each case being in three graduated quantities consisting of 8, 32, and 100 tons of CaO per acre or chemical equivalent quantities of the other substances.

Drainage water was collected during a period of two y ars and the sulfur content determined. It was found in every case in which the subsoil was present that the quantity of sulfur in the drainage water was much less than where there was no subsoil, except in the second year where MgO or $MgCO_3$ were used.

The effect of the 32-ton and 100-ton applications of CaO was to cut down the quantities of sulfur in the drainage water below that present in the leachings from the 8-ton treatment. The correspondingly large applications of MgO did not have this effect nor did the addition of $CaCO_3$ or $MgCO_3$. In fact, the application of magnesium compounds always increased the quantity of sulfur as compared with applications of calcium compounds.

Lyon and Bizzell (3) conducted lysimeter experiments with two soils, one a heavy clay loam and the other a silt loam. The lysimeters were 4 feet deep. The application of burnt lime at the rate of 3,000 pounds per acre did not increase the quantity of calcium in the drainage water of the former soil but it did in that of the latter. The soil from which there was no increased removal of lime by leaching contained more than twice as much calcium as the other. It contained a larger proportion of clay, which presumably gave it greater absorptive capacity.

In both soils magnesium was removed in greater quantity when the soil was limed. Potassium on the other hand was conserved in both soils by liming. In the case of the one soil the drainage water of which was analyzed for sodium that element was affected similarly to potassium by the application of lime.

In the finer textured soil, which was the one containing the larger quantity of calcium, the addition of lime did not increase the nitrate nitrogen in the drainage water but in the other soil it did. The effect on sulfur was directly contrary to the effect on nitrogen in that the soil in which nitrogen removal was increased by liming lost less sulfur and vice versa. It may be remarked that the soil in which liming did not increase the removal of sulfur had less apparent absorptive capacity than the other and that the failure of sulfur to be liberated was apparently not caused by absorption by the lower soil.

MacIntire (6) points out that there may be direct and substitutive absorption of lime. In the former case the Ca may be taken up by acid silicates or silicic acid, while in the latter the substitution of Ca for the alkali or alkali earth elements may take place and may or may not result in the loss of the liberated bases. He obtained little leaching of K or Na. The different forms of lime, CaO, $Ca(OH)_2$, and $CaCO_3$, showed little difference in substitutive effect.

The leachings of calcium were as large from the minimum or 8-ton $CaCO_3$ treatment as from the maximum or 100-ton treatment. In the case of treatments of equivalent quantities of CaO and $CaCO_3$ the former caused much larger losses of Ca in the leachings, especially with large treatments.

The above results were all obtained from 1-foot layers of top soil. In tanks which contained subsoil there was less loss of Ca in the leachings than from those containing only top soil.

Some unpublished data of MacIntire's indicate that treatments of MgO to top soil in quantities of 2,000 and 3,750 pounds per acre and of 8 to 100 tons resulted in conserving the loss of Ca in the leachings. The quantities of Mg in the leachings were, however, much greater than where lime was applied.

McHargue (4) analyzed the water of streams in Kentucky and elsewhere draining limestone areas and for purposes of comparison made analyses of streams draining other formations, notably sandstone and shale. He found that the former contained larger amounts of phosphorus, calcium, and nitrates, while the latter were usually richer in potassium and in some instances in magnesium, sodium, sulfur, and chlorin. The areas drained by these streams were covered by residual soils which are characteristic of the formations, those of the limestone areas in Kentucky being rather heavy clays while those of the coal measures farther east in that State and in western Pennsylvania were sandy. The potassium in the waters from the coal measures was more than twice that found in waters *from the limestone formations, which he attributes to differences in* the absorptive properties of the soils on the two areas. The limestone soils he states contained much more potassium in spite of the fact that they lost less in the drainage water.

As the limestone soils are richer in calcium than the others it would be natural that they would lose more. It is also probable that the limestone soils contain more nitrogen, so that the presence of large amounts of calcium can not necessarily be considered to be the cause of the larger removal of nitrate nitrogen.

SUMMARY.

Applications of calcium oxid and carbonate usually increase nitrification and removal of nitrogen in drainage water. In some soils there is no such result, which in some of the experiments reviewed is possibly to be accounted for by partial sterilization. In other cases it

may be explained by high absorptive properties of certain soils, by reason of which lime, in moderate quantities, has comparatively little effect on the composition of the soil solution and therefore on nitrification.

Gypsum appears to have a depressing effect on nitrification and nitrogen removal when applied in the comparatively large quantities in which the other forms of lime are usually applied, but there are exceptions to this. When used in the quantities that would be present in ordinary applications of acid phosphate there may not be such an effect, but lysimeter experiments have not been conducted with such quantities.

The effect of liming on the removal of sulfur in the drainage water is difficult to understand. Apparently when conditions are made more favorable for nitrification they are not always more favorable for sulfofication. In other words, when liming increases nitrification it may or may not promote sulfofication. The data do not permit any further generalization. There is some indication, however, that a subsoil may absorb much of the sulfate formed in the upper soil.

Excessive applications of calcium oxid may depress the sulfofying process but this is not true of equivalent applications of carbonates of calcium and magnesium. The influence of the oxid in this case may be due to partial sterilization of the soil. It would be interesting if figures for nitrogen in drainage water from the same soils were available. Magnesium oxid and carbonate are more potent in effecting removal of sulfur than are the same compounds of calcium.

Liming with oxid or carbonate has in many cases increased the removal of calcium in the drainage and in somewhat fewer instances it has not done so. Clay soils with great absorptive capacity either did not give off calcium when limed or did so to less degree than did more sandy soils. It seems probable that the magnitude of the absorptive capacity determines the ability of a soil to prevent the liberation of calcium when lime is applied. Magnesium appears always to be liberated when a soil is limed. Gypsum invariably increases removal of calcium and probably of magnesium altho there are less data for the latter substance.

Potassium rarely appears in larger quantities when a soil is limed with carbonate or oxid. There may be some soils in which potassium is thus liberated but this does not appear to be a normal circumstance, especially when the drainage passes thru a subsoil. Gypsum, on the other hand, more frequently effects a liberation of potassium.

So far as phosphorus is concerned there is to be found so little in

drainage water that nothing has been learned regarding it by means *of lysimeter experiments.*

LITERATURE CITED.

1. BROUGHTON, L. B. How lime is distributed through and lost from soil. Md. Agr. Expt. Sta. Bul. 166, p. 285–326. 1912.
2. ECKART, C. F. Lysimeter experiments. Hawaiian Sugar Planters' Assn. Expt. Sta. Bul. 19, p. 1–31. 1906.
3. LYON, T. L., and BIZZELL, J. A. Lysimeter experiments. Cornell Univ. Agr. Expt. Sta. Memoir 12, p. 7–113. 1918. Also unpublished data.
4. MCHARGUE, J. S. The removal of mineral plant food by natural drainage waters. Unpublished.
5. MACINTIRE, W. H., WILLIS, L. G., and HOLDING, W. A. The divergent effects of lime and magnesia upon the conservation of soil sulfur. *In* Soil Sci., v. 4, p. 231–235. 1917.
6. MACINTIRE, W. H. The carbonation of burnt lime in soils. *In* Soil Sci., v. 7, p. 325–446. 1919. Also unpublished data.
7. PECK, S. S. Lysimeter experiments. Hawaiian Sugar Planters' Assn. Expt. Sta. Bul. 37, p. 3–38. 1911.
8. TACKE, BR., IMMENDORFF, H., and MINSSEN, H. Untersuchungen über die Zusammensetzung der Sickerwässer aus nichtgedungtem und aus gedungtem Moorboden mit besonderer Berücksichtigung der Stickstoffverbindungen. *In* Landw. Jahrb., Bd. 27, Erganzungsband IV, S. 349–391. 1898.

AGRONOMIC AFFAIRS.

BACK NUMBERS OF THE JOURNAL.

The editor has in stock varying numbers of each issue of the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY and also copies of the *Proceedings,* four volumes of which were issued prior to the establishment of the JOURNAL in 1913. It is desirable that the storage space occupied by these volumes be reduced, and also that the Society obtain such funds from them as may be possible. Members who have joined in recent years are urged to purchase as many of these volumes as they feel they can afford and can use to advantage. Copies can be seen in almost any of the experiment station libraries, and members can thus decide just which volumes are likely to prove most valuable to them. The reduced prices at which back volumes can be purchased by members will be quoted on request by the secretary-treasurer or the editor. In general, remittance drawn to the American Society of Agronomy should accompany the order. As some of the volumes are in stock in limited numbers only, agronomists will do well to make sure that college and station libraries have complete sets.

More copies are on hand of many individual issues of the JOURNAL than can be used in making up complete volumes. Members who keep a file of the publication can usually obtain missing numbers on request addressed to the editor. So far as these can be supplied without breaking volumes, they will be sent free. On the other hand, those who do not wish to maintain a file of the JOURNAL will confer a favor on the Society by returning to the editor their copies of Volume 5, No. 1, and Volume 8, No. 4, the stock of which is particularly low. Complete copies of Volume 8 or any of the individual numbers of that volume can be used to advantage.

MEMBERSHIP CHANGES.

The membership reported in the February JOURNAL was 582. Since that report, 22 new members have been added and 8 members have been reinstated, while 3 have resigned. These changes have resulted in a net gain of 27, making the present membership 609. This is still far short of what it should be, and members everywhere

are urged to use their best efforts to bring the Society to the attention of agronomic workers who do not now belong to it.

NOTES AND NEWS.

Elmer D. Ball, professor of zoology at Iowa State College and assistant secretary of the United States Department of Agriculture since June, 1920, has been retained in that position by Secretary Wallace.

D. W. Frear, formerly connected with the Greenville, Tex., field station of the Bureau of Plant Industry, is now extension specialist in field crops at the University of Missouri.

R. B. Lowry is associate professor of soils at the University of Tennessee, instead of instructor in soils as stated in the February JOURNAL.

Edwin T. Meredith, who has been Secretary of Agriculture since February, 1920, was tendered a farewell reception by about 600 of the scientific and technical employes of the Department of Agriculture on February 16. Mr. Meredith was presented with a bound volume containing an expression of the appreciation of these men for the interest in and understanding of their work manifested by him during his term of office, and of their regret that his stay in the Department was of necessity so short. This appreciation was followed by the signatures of the technical workers concerned.

Charles E. Thorne, who has been director of the Ohio Agricultural Experiment Station since June, 1887, has resigned the directorship, but will remain in charge of the investigations in soil fertility. C. G. Williams, who has been agronomist of the station since 1902 and associate director since 1917, has been appointed acting director.

Henry C. Wallace, editor of *Wallaces' Farmer,* Des Moines, Iowa, and a graduate of Iowa State College, has been named by President Harding as Secretary of Agriculture, succeeding Edwin T. Meredith, owner of *Successful Farming,* also of Des Moines. Mr. Wallace was for a time a member of the faculty of Iowa State College, but has for many years been engaged in editorial work on Wallaces' *Farmer* and for the past several years has been its managing editor. He has been active in progressive movements for the benefit of farmers and was a frequent adviser of President Harding on agricultural matters during the recent campaign.

C. W. Warburton, agronomist in the Bureau of Plant Industry, has been detailed by the Secretary of Agriculture to supervise the field work in connection with the making of seed loans to farmers in the drouth-stricken districts, out of the $2,000,000 fund authorized by the appropriation act for the Department of Agriculture approved March 3, 1921. Mr. Warburton left Washington March 12 to establish a temporary office at Fargo, N. Dak., where applications for loans will be received. The general supervision of this activity in Washington is vested in a committee, of which L. M. Estabrook, chief of the bureau of crop estimates, is chairman.

N. E. Winters, who has been engaged in graduate study at Cornell University for the past several months, is again located at Charlotte, N. C., in extension work for the North Carolina A. & M. College.

The appropriation act for the Department of Agriculture for the fiscal year beginning July 1, 1921, approved March 3, 1920, contains few new features or marked changes. It provides for two new supervisory officers, a director of scientific work and a director of regulation, at $5,000 each. In general, the appropriations for agronomic work are practically the same as those of the current year. An unusual feature is the $2,000,000 appropriation for seed loans to farmers, referred to above.

MEETING OF THE NEW ENGLAND SECTION.

The seventh annual meeting of the New England section of the American Society of Agronomy was held at the Parker House, Boston, Mass., Nov. 13, 1920. The meeting was presided over by Prof. W. L. Slate, Jr., president of the section. Those present included Profs. Slate, Dorsey, and Owens of the Connecticut Agricultural College; Prof. G. E. Simmons of the University of Maine; Prof. M. Gale Eastman of the New Hampshire State College; and Prof. A. B. Beaumont and Mr. C. G. Crocker of the Massachusetts Agricultural College. The program included papers on the teaching of soils and field crops and reports on the fertility school for county agents, extension workers, and agronomists, which was conducted at the Rhode Island College in August, 1920. Most of the time was spent in discussing teaching problems met in the introductory courses in soils and field crops. Prof. W. L. Slate, Jr., of Connecticut, was reelected president, and Prof. A. B. Beaumont, of Massachusetts, was elected secretary.

ASSOCIATION OF SOUTHERN AGRICULTURAL WORKERS.

The twenty-second annual convention of the Association of Southern Agricultural Workers was held at Lexington, Ky., February 15–17, 1921. General sessions were held in the mornings, while the various sections met in the afternoon and evening. Section I, Field Crops and Fertilizers, of which Prof. George Roberts of the University of Kentucky was president and Prof. R. Y. Winters of the North Carolina A. & M. College was secretary, met on February 15 and 16. The section voted to organize as the Southern Section of the American Society of Agronomy, and this action was heartily approved by the general association. The following program was presented:

Factors in Crop Production Affecting the Efficiency of Fertilizers—Dean C. B. Williams, chief, division of agronomy, North Carolina Agricultural Experiment Station.

Ten Years of Experiments on Methods of Cultivating Corn—Prof. E. J. Kinney, agronomist, University of Kentucky.

Field Comparisons of Phosphatic Materials—W. F. Pate, soils agronomist, North Carolina Agricultural Experiment Station.

Report of the Committee on Coordinating Soil Fertility and Field-Crop Work in the South—Prof. G. F. Kidder, agronomist and assistant director, Louisiana Agricultural Experiment Station.

Ten Years' Selection of Light and Heavy Cotton Seed—Prof. E. F. Cauthen, agriculturist, Alabama Agricultural Experiment Station.

The Prevalence of Corn Root-Rot and Selection for Resistance as a Means of Control—Dr. W. D. Valleau, University of Kentucky.

The Place of Sweet Sorghums in Southern Agriculture—M. W. Hensel, U. S. Office of Sugar Plant Investigations and North Carolina Agricultural Experiment Station.

Results of Various Methods of Combined Planting of Corn and Soybeans—Prof. E. J. Kinney, agronomist, University of Kentucky.

Tobacco Root-Rot and Selection for Resistance—Dr. W. D. Valleau and R. H. Milton, University of Kentucky.

Effect of Fertilizer on Germination and Seedling Growth—Prof. M. E. Sherwin, head of soils department, North Carolina State College.

Some Outstanding Results from Our Cotton Inheritance Studies—Dr. R. Y. Winters, agronomist in plant breeding, North Carolina Agricultural Experiment Station.

The Influence of High and Low Ear, Long and Short Shuck, and Loose and Tight Shuck, on Yield of Corn—Dr. H. B. Brown, plant breeder, Mississippi Agricultural Experiment Station.

Length and Strength of Cotton Fiber as Affected by Place Effect—H. F. O'Kelly, assistant agronomist, Mississippi Agricultural Experiment Station.

The Value of Physical Character in the Selection of Seed for the Control of Corn Root-Rot.—Dr. W. D. Valleau and E. N. Fergus, University of Kentucky.

WESTERN CANADIAN SOCIETY OF AGRONOMY.

The first regular annual meeting of the Western Canadian Society of Agronomy was held at the University of Alberta, Edmonton, December 28–30, 1920. The sessions were attended by representatives of Alberta College of Agriculture, Manitoba Agricultural College, Saskatchewan College of Agriculture, Alberta Department of Agriculture, the several Alberta Schools of Agriculture, the Central Experimental Farm, the Dominion Experimental Farms, the Dominion Seed Branch, and by several men interested in agronomy who have no official connection. The meeting was an enthusiastic one, and a considerable number of new members was added. The object of the Society is to encourage investigational work in soils and crops and to disseminate knowledge concerning these subjects; to obtain the highest standard of instruction in agronomy at the agricultural institutions in the prairie provinces; and to unify and standardize as much as possible the methods used by investigators in this district. The following papers were presented:

Scope and Arrangement of Studies in the Degree Course in Agronomy, by T. J. Harrison, professor of field husbandry, Manitoba Agricultural College.

The Distribution of Studies in the Degree Course in Agriculture, by R. Newton, assistant professor of field husbandry, Alberta College of Agriculture.

The Technique of Field Husbandry, by Manley Champlin, professor of field husbandry, Saskatchewan College of Agriculture.

The Past, Present, and Future of Field Crop Experimentation, by M. J. Tinline, superintendent of the experimental farm, Scott, Sask.

The Place of Research in Agriculture, by Dean E. A. Howes, Alberta College of Agriculture.

The Biologic Strains of Stem Rust in Western Canada, by Miss Margaret Newton, Saskatchewan College of Agriculture.

Drought Resistance of Farm Crops, by E. S. Hopkins, Central Experimental Farms.

Soil Drifting in Manitoba, by J. B. Ellis, instructor in crop management, Manitoba Agricultural College.

Soil Drifting in Saskatchewan, by R. Hansen, professor of soils, Saskatchewan College of Agriculture.

Soil Drifting in Alberta, by W. H. Fairfield, superintendent of the experimental farm, Lethbridge, Alta.

Methods of Breeding in Forage Plants, by Dr. M. O. Malte, Central Experimental Farm.

A Study of the Influence of the Root System in Promoting Hardiness in Alfalfa, by Prof. W. Southworth, Manitoba Agricultural College (read by J. H. Ellis).

Methods of Distributing Pure Seed in Alberta, by G. H. Cutler, professor of field husbandry, University of Alberta.

Education Takes the Field, by E. A. Ottewell, extension department, University of Alberta.

The Effect of Premature Harvesting on the Wheat Kernel, by Dr. Charles E. Saunders, Central Experimental Farm.

Symbiotic Nitrogen Fixation by Leguminous Plants with Special Reference to Bacteria Concerned, by R. Hansen, professor of soils, Saskatchewan College of Agriculture.

Soils of the Peace River District, by Dr. F. A. Wyatt, professor of soils, Alberta College of Agriculture.

The Quality of Silage Produced in Barrels,[1] by R. Newton, assistant professor of field husbandry, University of Alberta.

The need for careful research in advance of instruction and extension was urged by President Tory of the University of Alberta at a banquet tendered to the members of the association by the university. This need was also emphasized by Dean Howes in his paper, "The Place of Research in Agriculture." Dean Howes, however, cautioned against the extreme modesty or conservatism which withheld results from the public and thus curtailed the benefits of research.

Officers elected for the year 1921 are as follows: Prof. T. J. Harrison, Manitoba Agricultural College, president; Prof. G. H. Cutler, University of Alberta, vice-president; Prof. R. Hansen, University of Saskatchewan, secretary-treasurer; and F. S. Grisdale, principal Olds Agricultural School, and W. C. McKillican, superintendent Brandon Experimental Farm, additional members of the executive committee.

Arrangements were made with the Alberta Department of Agriculture to publish the papers presented at the meeting, and those of general interest to farmers will also be published in bulletin form. A limited numbers of copies of the proceedings will be available to members of the American Society of Agronomy, who can obtain further particulars by writing to Prof. G. H. Cutler, University of Alberta, Edmonton, Alta.

[1] This paper was published in JOUR. AMER. SOC. AGRON., v. 13, no. 1, p. 1-11. 1921.—Ed.

JOURNAL

OF THE

American Society of Agronomy

Vol. 13. April, 1921. No. 4

THE NATURE OF SOIL ACIDITY WITH REGARD TO ITS QUANTITATIVE DETERMINATION.[1]

W. H. MacIntire.[2]

It is probably true that, in recent years, no one phase of soil chemistry has received more attention than the problem variously referred to as lime requirement, soil acidity, or lime absorption coefficient. The problem can hardly be considered, however, as having solely a chemical or physico-chemical basis in its relation to soil fertility, for it is closely correlated with, if not inseparable from, both bacteriological and plant physiological considerations. Until very recently, if even now, little effort has been made or opportunity offered for concerted, authentic action to clarify this intricate problem and to adopt terms or phrases which convey a definite and accepted meaning of the several possible causes and the possible differential intensities of these reactions responsible for the soil condition known most commonly as acid.

Lime requirement for what? For effecting a chemically neutral or near-neutral condition as determined by some arbitrary chemical procedure in the laboratory; for optimum biological development, as recorded in the laboratory; or for maximum growth of certain specific and responsive plants in pots, cylinders, or plats? Some of these considerations were advanced by the writer to the Association of Official Agricultural Chemists at its 1916 meeting in a paper entitled

[1] Contribution from the University of Tennessee Agricultural Experiment Station, Knoxville, Tenn. Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1921.

[2] Soil chemist, University of Tennessee Agricultural Experiment Station.

"Status of the Problem of Lime Requirement" (40).[3] At that time, that Association recognized the problem, which has since been studied collaboratively under the Association's referee system.

The problem of the causes responsible for the genesis and continued occurrence of the acid characteristics in soils is admittedly a complex one. The trend of the investigations has probably often followed lines suggested by conceptions and hypotheses, as assumed by various workers. These several concepts have been made of record and reflected by the several methods advanced for the qualitative and quantitative determinations of the total, as well as the supposedly more active and less active fractions of the total acidity. In the past, the study of so-called "soil acidity" took direction largely from the isolated and academic viewpoint of the laboratory worker seeking to establish reactions and to determine their speed and extent. Nevertheless, in much of the more recent work, special emphasis has been placed upon correlations with bacterial and plant-response factors. It is the purpose of this paper to offer briefly the chronological development of most of the viewpoints and hypotheses advanced and conclusions maintained, with or without subsequent modification, by those who have reported upon this interesting and absorbing topic.

The beginning of the studies wherein it was shown that siliceous admixtures, including soil, could effect the removal of solutes from solvents might be assigned to the year 1739 when it was determined by Hales (23) that sea water, after percolation thru stoneware, was deprived in part of its several salts. Probably it is better to date from the work of Way (71), who showed, in 1850, that combinations of strong bases with both weak and strong acid radicals would be disrupted when their neutral aqueous solutions were allowed contact with soils. The fact that potassium, sodium, calcium, and magnesium salts of several acids would be disrupted, thru adsorption of the basic radicals, and that the liberated acid radicals could be leached, has served as the basis of certain types of quantitative analytical procedure. The further fact that the degree of dissociation, as influenced by the relative strength of a base when combined with acid radicals of different strength, governs both the speed and ultimate extent of the basic ionic absorption phenomenon, has further served as a basis for amplification of methods, by which it is sought to determine the differential occurrence of acids or acid properties of varying "avidity."

It has been universally recognized that, whether the acidity of soil

[3] Reference by number is to "Literature cited," p. 158.

is to be attributed to true acids, acid salts, or solids possessing absorptive and acid-indicating properties, the causative substances are so insoluble as to preclude the possibility of their appreciable extraction by distilled water leaching when measured by the ordinary chromophoric indicator. On the other hand, such separation could not be effected by the use of carbonated distilled water, in simulating free soil water, for the basic materials brought to the solution from the concentrated film water and by hydrolysis of the various alkali silicates, and more particularly the alkali-earth silicates, would effect an immediate neutralization of any dissolved acid. Hence, the quantitative methods developed have been directed toward various reactions brought about during contact of soil and treatment followed by a quick recovery and determination of the leached or evolved end-products of the reaction so indicated.

The most commonly known qualitative method of determining a soil's reaction is that which utilizes litmus paper. Wahnschaffe (70) appears to have been the first to use litmus paper as a qualitative means of detecting an acid condition in soils.

Van Bemmelen (5) was a pronounced advocate of the theory of adsorption by the colloidal materials characterisic of acid soils. He believed that substitution for liberated bases occurred in equivalent ratios, a conception not substantiated when applied to treatment of soils with $CaCO_3$ and $MgCO_3$. It was van Bemmelen's belief that silicic acid, colloidal silicates, iron oxids, and humic materials are responsible for the indications of acidity as obtained by the procedures involving treatments with solutions of neutral salts.

Halleman (24) measured the readiness with which calcic compounds suffered hydrolysis when treated twenty-four hours with saturated carbonated water, as an indication of the need of a soil for basic additions.

Tacke (60), conceiving the acidity of soils to be due to the presence of a true acid, used the CO_2 liberated from an agitated mixture of soil and $CaCO_3$, in an atmosphere of hydrogen, as an index to "lime requirement." The continuity of evolution of CO_2 under long-continued contact, however, was not emphasized by Tacke.

Wheeler, Hartwell, and Sargent (72), in an effort to evolve a simple titration procedure, utilized N-10 ammonium hydroxid for treatment and determination of the excess unfixed, or unneutralized, after a period of contact extending over forty-two hours. These workers also reported their studies relative to the quantitative liberation of CO_2 from distilled water suspensions of $CaCO_3$ with soil, in a manner

similar to that employed by Tacke, and pointed out the influence of time upon the speed and ultimate extent of the reaction. They likewise studied the same procedure when heat was introduced, as was later done by Ames and Schollenberger (2), tho the latter workers used decreased pressure to lower the boiling point.

Veitch (67) advanced a procedure for the determination of the acid properties of the soil, using the principle of effecting an equilibrium between the acid materials and the minimum of dissolved $Ca(OH)_2$ capable of indicating alkalinity, by use of phenolphthalein as an indicator, after contact with the soil. It was his belief that by such treatment the "total apparent acidity" could be determined. This "total apparent acidity" he attributed as being "due almost entirely to insoluble organic acids and to absorption by the non-acid materials." In this and later work, consideration was given to correlation between laboratory findings and field results. Veitch wrote:

> While the reaction affects the chemical and the physical condition of the soil to a considerable extent, the growth of plants is more directly affected by the action of the acid on the plant roots and upon the micro-organisms of the soil. . . . Even very acid soils will, on long-continued treatments with much water, yield an extract which, on concentration, will give an alkaline reaction with this indicator (phenolphthalein).

Hopkins, Knox, and Pettit (29) offered a quantitative method based upon the liberation and factoring of the amount of HCl (or $FeCl_3$ or $AlCl_3$) found as a result of the contact of soil suspensions with sodium chloride solutions. Chemical equivalence was assumed in the conversion of the absorption coefficient to terms of $CaCO_3$. These investigators stated:

> The acids of the soils are themselves very difficultly soluble and it is practically impossible to completely extract them from the soil with distilled water, even though large quantities of water be percolated through the soil; but, when a mineral salt solution is added to the soil, the acid apparently unites with the mineral base, evidently liberating the mineral acid, or an acid salt which, of course, is perfectly soluble, and whose titrating power furnishes a very satisfactory basis for determining the total acidity of the soils.

Potassium nitrate was later substituted for sodium chlorid.

In commenting upon the Hopkins method at the time of its presentation and referring to his own method previously submitted for publication, Veitch (68) stated:

> It seems to me that the first thing we need to do is to define acidity and settle upon an indicator which shall be the standard by which to judge the reaction of soils. Many of the acids that may be present in soils are so weak that they give no certain reaction with most indicators, except in concentrations greater than probably exist in most acid soils.

In a further valuable and fundamental contribution to the subject, Veitch (69) studied the method of Hopkins in parallel with his own. He concluded that the acidity generated by the Hopkins method was due, in the main, to aluminum chlorid. He further concludes that "acid organic matter" has not been shown to liberate equivalent amounts of free mineral acids. Veitch attempted to correlate the partial or complete neutralization of "apparent acidity" with variation in crop yields and was of the opinion "that we are dealing with several kinds of 'acidity,' which effect fertility very unequally." Veitch differentiated between "active or actual acidity" due to relatively soluble organic and inorganic acids and salts; and "inactive or negative acidity reaching in some soils to actual neutrality, as determined by the usual indicators." The latter acidity he attributes primarily to "easily attacked hydrated or colloidal silicates and many non-acid organic compounds" possessing basic affinity. Veitch concluded that "We may determine the total occurrence of acidity by the lime water method and by subtracting the acidity determined by the sodium chloride method, we have acidity due to insoluble organic matter."

Cameron and Bell (11) offered researches demonstrating that physical absorption could effect liberation of free acid thru selective attraction for the basic ion in a neutral aqueous medium. Along with other interesting analogies, they demonstrated that carefully treated cotton would absorb the base from filter paper, previously impregnated with a neutral litmus solution. From this observation they concluded that the acidity indicated by the litmus paper test may not represent native free soil acidity.

Knisely (34) recommended the use of litmus paper as a qualitative procedure for determining "the acid condition of the soil (which) is due to a lack of basic substances."

Sullivan (59) repeated the earlier experiments of Kohler (1903) and corroborated the findings as to the ability of acid soils to liberate hydrochloric acid from neutral solutions of sodium and magnesium chlorids; but Sullivan attributed the acidity found to the presence of ferric and aluminic chlorids, which readily hydrolyze in dilute aqueous solution.

Patten and Waggaman (48), without advancing a method of their own, published an exhaustive compilation of the researches upon the absorptive properties of soils and siliceous materials for both solids and gases. This work is of interest because of its bearing upon the fundamental principles involved in the adaptation of the neutral solu-

tions of the several salts, which have been used for contact treatments and acid liberation by a number of workers.

Süchting (58) assumed that the soil and $CaCO_3$ contact treatment employed by Tacke resulted in some decomposition of organic matter, with CO_2 liberation, which he believed should not be ascribed to acidity. He modified Tacke's procedure by discarding the CO_2 liberated from the soil and agitated carbonate mixture, following this step by determining the residual carbonate and assuming the difference between initial and residual to be attributable to decomposition effected by true soil acids.

Blair and Macy (7) used the Veitch procedure in a study of Florida soils. It was their belief that the major portion of the acidity encountered was due to the formation of organic acids in the soil.

Stoddart (57) studied the parallel between soil acidity and poverty of phosphate soluble in N/5 HNO_3 and endeavored to establish a "causal relationship." His explanation of the parallel was:

> The soil acid acts upon the readily available phosphates, such as the calcium phosphates, at a more rapid rate than the normal neutral and alkaline soil moisture, and when once in solution these phosphates are readily washed out by the heavy rains, or are fixed by iron and aluminum compounds, that is, precipitated and rendered unavailable as insoluble iron or aluminum phosphate. This paucity of phosphates soluble in N/5 HNO_3 is a measure of acidity or its detrimental residual effects.

This conception is of interest when contrasted with the later work on aluminum toxicity and its elimination by phosphatic manures as reported by Hartwell and Pember (26), Conner (14), and Mirasol (43).

Baumann (4) reported findings which led him to the conclusion that the acidity characteristic of peats is to be attributed to absorption by organic colloidal materials.

Lipman (36) suggested the possibility of determining the intensity of soil acidity by measuring the depressive influence of added soil upon biological activities in culture media.

Hopkins (28) wrote, "Usually these soil acids exist in part, at least, as organic acids," but he found that even were all of the organic carbon of the subsoil in the form of "humic" acid, it would be equal to less than half of the acidity found and in some cases but one-sixth of the amount determined. Further,

> Acid silicates formed from polysilicates, from which some basic element may have been removed and replaced with acid hydrogen, by reaction with soluble organic acids, or possibly by long continued weak action of drainage water charged with carbonic acid, do exist in the soil and the evidence thus far se-

cured indicates that they account for most of the acidity of soils that are, at the same time, strongly acid and very deficient in humus.

Hopkins further states, somewhat at variance with other previous and subsequent opinions,

The legume plants themselves are not so sensitive to acid conditions, but, rather, the bacteria depended upon to furnish nitrogen; . . .

Gregoire (22) assumed that free soil acids would liberate iodine from Kjeldahl's solution (KI, KIO_3, and $Na_2S_2O_3$) and that the residual thiosulfate determination would serve as a measure of the extent of the reaction. (It should be noted that the readily hydrolyzed salts of iron and aluminum will function in like manner.)

Bizzell and Lyon (6) made a study of the method of Albert (3), who proposed the distillation of ammonia from an addition of ammonium chlorid and a definite amount of $Ba(OH)_2$, upon the assumption that the excess of barium hydrate above the amount absorbed by the soil would liberate a chemical equivalence of NH_3. These workers found that soils boiled with NH_4Cl would yield free ammonia when otherwise untreated, and they further established the fact that the maximum absorption of barium hydrate requires time and heat rather than being immediately effected and upon this basis they advanced a modification. They are of the opinion that "The true nature of the acidity is not understood."

Moulton and Trowbridge (44) studied the results offered by Bizzell and Lyon. They contend that the data secured in their studies "seems to establish the fact that the lime requirement found by the method of Bizzell and Lyon is proportionate to the $Ba(OH)_2$ used and not to the acidity of the soil."

Jones (33) advanced a procedure wherein the extent of removal of calcium from an aqueous solution of calcium acetate, when factored through empirical means, was taken as an index of lime absorption.

Coville (16) tested samples of humifying leaves and green manures and noted that they are acid and that they impart to soils an acidity or base deficiency in the incipient stage; but he points out the remedial residual effect of the basic elements held by the readily oxidized organic acid radicals. In this connection it might be well to mention the well known tendency of barnyard manure to maintain alkalinity or neutrality in a soil in a greater measure than could be attributed to the added calcium or other basic elements.

Parker (46, 47) concluded that free acidity results temporarily when fertilizers such as KCl are added to a soil, as a result of the

hydrolysis of KCl and the adsorption of the basic ions ($KCl + HOH \leftrightarrows KOH$ (absorbed) and HCl); the free acid, however, being quickly combined with native soil alkali earth bases or, in their absence, with the amphoteric elements, particularly iron and aluminum.

Abbott, Conner, and Smalley (1) encountered a somewhat unusual condition in studying soils of high organic content and low alkali-earth content. They found toxicity and excessive nitrification, coincident with sterility, and a soil solution excessively acid due to the presence of aluminum nitrate. Tho no acid other than that combined with aluminum was found, nevertheless the effect was that of free acid, an excess of H-ions, due to hydrolysis of aluminum nitrate.

Loew (37) used the liberation of iodine from a boiling solution of potassium iodide in contact with soils as an indication of an acid condition. Loew is of the opinion that the so-called acidity may be due, in part, to "humic acid," but that the preponderating acidity of the clay soils in Porto Rico is due to mineral compounds. He believed that "pure clay behaves like an acid," for which he suggests the designation "argillic." Loew suggests the use of aqueous solutions of sodium or potassium acetate in soil contact and the determination and calculation of the liberated acid in the filtrate to $CaCO_3$ equivalence.

Following a study based upon KCl absorption studies, Daikuhara (17) concluded that the acidity indications from humic acid were meager and he stressed the colloidal properties of iron and aluminum compounds.

In studying the influence of some organic acids, possibly formed from incorporated green manures and also added c. p. organic acids, Temple (61) concluded "that the danger of soil injury in this manner is very small."

MacIntire, Willis, and Hardy (41) found a wide variation between the amount of acidity indications when judged by the differentials between the chemical equivalences of $CaCO_3$ and $MgCO_3$ absorptions and carbonate decompositions. They further determined that the neutralization of the lime requirement indications obtained by the Veitch procedure would not inhibit extensive further fixation of $MgCO_3$; and that strong alkalinity induced by an 8-ton CaO equivalent of $MgCO_3$, above the Veitch indication, would not preclude a further extensive fixation of $MgCO_3$. Similar findings were likewise obtained when using sands, silt, clay, and kaolin, wherein the organic matter factor was eliminated. These investigators ignited siliceous and titanic materials with excesses of $CaCO_3$ and $MgCO_3$ for periods of 8 and 16 hours and then restored the moisture condition, after

which contact was permitted during a period of 133 days. The fact that such preliminary treatment with subsequent contacts was followed by the evolution of CO_2 from the added carbonates led these workers to conclude that silicic acid was the only acid material to which true acidity could be attributed, in these instances.

Harris (25) made a number of parallel experiments with soils and kaolin, wherein practically no organic compounds were present. His results led him to the conclusion that "The behavior of the soil towards neutral salts is not due to the presence of insoluble organic acids, or even to the presence of organic matter at all, but to inorganic compounds, probably hydrated silicates." Harris further showed that sodium was absorbed by the soil and kaolin in distinctly different amounts, according to its combined acid radical, when added in molar equivalence and equal concentration. Because of this, he pointed to the unreliability of the "results of analytical methods for determining the 'lime requirement' of a soil, unless the method employed be the material that is to be used in the field."

Hutchinson and McLennan (32) believed that, since in most liming operations the absorption or neutralization of the carbonate proceeds thru action of calcium bicarbonate upon the acid soils, it would seem logical to treat the soil with this solution. They permitted contact of suspended acid soil with calcium bicarbonate of definite strength for a definite period. After filtration the determination of residual bicarbonate was carried out by direct titration. These workers supplemented their laboratory investigations with pot studies and believed that they were able to establish some correlation.

MacIntire (38), carrying out the same thought, evaporated soil with a definite amount of $CaH_2(CO_3)_2$ and determined the CO_2 of the precipitated residual $CaCO_3$. He pointed to the fact that this method, insofar as he could establish, would give definite laboratory results capable of close checking, but that the procedure did not record the continued propensity of the soil to effect decomposition of calcium carbonate. This continued reaction between soil and alkali-earth carbonate, as demonstrated by laboratory and field results, is one which may extend over a period of years.

Truog (62) advanced a qualitative test based upon the liberation of H_2S from zinc sulfid when boiled with acid soil, particularly when the reaction is accelerated by the absorption of calcium and liberation of HCl from simultaneously added $CaCl_2$. To this procedure he accredits the faculty of the determination of acidity in an approximation to the quantitative requirement of practice. In a supplement to his bulletin Truog states:

The acids causing soil acidity vary greatly in strength. Some soils contain considerable amounts of acid which are so weak that they cause little injury. For this reason an absolute quantitative method does not indicate the amount of lime which should be used.

Lint (35) studied the increase of lime requirement in leached soil cultures in the laboratory, as induced by addition of flowers of sulfur, using the Jones acetate procedure as a measure of changes induced. It appeared from his results that the alkali-earth bases had combined with the sulfuric acid engendered and that the decrease in the native store of these elements was responsible for an increased absorption of lime from the added calcium acetate used in making the determination.

Clark (12) contributed a classic dissertation entitled, "The Constitution of the Natural Silicates." This treatise has intimate relationship to soil acidity studies, since, by his interpretations, it is easy to comprehend how neutral or alkaline silicates may become of acid or base absorbing nature, thru the removal of bases by mineral acids, as was done by Harris, or their treatments with carbonated water, as was done by Truog, the writer, and others. To pure silicate formations, Clark attributed a definite chemical structure and assigned to various silicates a composition representing them to be true acid salts of the several possible silicic combinations.

In this connection it is interesting to note the observations of Brown and Johnson (10), relative to the influence of grinding upon the indication secured thru the use of the Veitch procedure. These workers reported that the finely ground soil gave an alkaline reaction as compared to an acid condition indicated prior to grinding. This would be expected in the case of new soils of the glaciated regions where grinding would disrupt undisintegrated particles, yielding fresh surfaces or more readily hydrolizable compounds; or again, where calcite or similar materials might be included within quartz crystals. On the other hand, working with highly siliceous soils, Cook (14) found that grinding increased acidity. This is in harmony with the findings of MacIntire, Willis, and Hardy (41) previously mentioned, in which it was shown that pure quartz sand would decompose $CaCO_3$ and $MgCO_3$ somewhat in proportion to the fineness of the siliceous material.

Ruprecht and Morse (52) conclude that the acid condition of soils brought about by the use of ammonium sulfate is not due to the accumulation of free acid; that the sulfuric acid engendered from such treatments results primarily in effecting a lime deficiency; and

that upon depletion of lime salts the excess of acid combines with iron and aluminum, forming sulfates of these elements which impart acidity and toxicity to the soil.

In studying the ammonium-sulfate-treated plats of the Pennsylvania station, White (73) concluded that an assumed increase in occurrence of "humic acid" is responsible for the increased acidity of these plats, as measured by the procedure of Veitch (67). White also offers certain refinements as modifications of the Veitch procedure.

Frear (18) offered a comprehensive treatise upon "Sour Soils and Liming" in which a general review is offered of the causes attributed as being responsible for the occurrence of acid soils. He concludes that the investigations reported justify the conclusion "that the acid-acting substances are probably numerous rather than few and simple."

Gillespie (19) conceded that the total amount of acidity present is an important factor, but gives consideration to the intensity of the acidity, i.e., H-ion concentration, for the determination of which he used the hydrogen electrode and the colorimetric procedure of Lubs and Clark.

MacIntire (39), in reporting upon the factors that influence lime and magnesia requirements of soils, showed that alkaline kaolin (alkaline to litmus) and clay would evolve CO_2 from moist contact treatments of $CaCO_3$ and $MgCO_3$, particularly the latter, and that pure quartz and rutile (TiO_2) would affect the same evolution both at low temperature over long periods and upon short periods of boiling. Emphasis was also given to the fact that silicates of calcium and magnesium formed from contact of excess of SiO_2, or silicates, with the alkali-earth carbonates could readily be decomposed, if the condition of the active mass were reversed; i.e., when the silicates were treated with carbonated water. It was also shown that preliminary treatments with sodium hydrate, followed by leaching, and oxygen combustion of alkaline earth did not preclude further decomposition of alkaline earth carbonates, as measured by CO_2 evolutions, when moist contact was permitted for periods of 133 and 473 days. Differentiation was further made between the immediate decomposition of $CaCO_3$ and $MgCO_3$ by soils and the continued decomposition, as evidenced by the Pennsylvania and Tennessee data.

As a development of these studies and limiting the discussion to rock-derived soils, and with the conception that the term "soil acidity" denotes a soil's ability to decompose calcium carbonate, as would

be the conception for practical application, MacIntire advanced certain conclusions relative to the cause and effect of soil acidity.

> First it must be emphasized that, *in uncarbonated water* solution, SiO_2 proves to be a stronger acid radical than CO_2 of earthy carbonates. The reversal of conditions is effected when there is present an excess of CO_2 gas. . . . It is probably true, as indicated by data given, that both of these conditions actually exist at different times under field conditions. . . . That we do have free mineral acid—silicic acid—in soils, is true . . . , this acid effects appreciable and long-continued decomposition of $CaCO_3$ and excessive decomposition of $MgCO_3$ and (that) its acid salts—clays—are even more acid than the relatively insoluble acid itself.

This reference to acidity applied to the quantitative determination of the amount of acidity as recorded by the usual indicators in titration procedures and not to the intensity factor as would be determined by the hydrogen ion concentration. In considering the growing plant in the environmet of an acid soil, it was pointed out:

> Thus we have the lime-loving plants which do not thrive, *not because their nutrient solutions are acid, but because the available solutions are not sufficiently concentrated in their $CaCO_3$ content*, or possibly in neutral salts of root-formed acids which act directly upon the bases of the unhydrolyzed silicates. . . . It is conceivable that rapidly growing plants would extract lime and also other bases from the soil solution more rapidly than the soil moisture could effect the hydrolysis of the silicates, from which an acid soil principally derives the bases which are offered to the plants.

Two years later, Truog (65) recorded what would seem to be a concordant, if not identical, viewpoint. The concordance extends, however, only thru consideration of soil supply and plant needs in an acid soil, since the Tennessee station offering did not extend to a consideration of the functions of the calcium salts within the plant. Without citing the thought set forth in the two preceding sentences quoted and presumably having failed to note it, or having considered it as not being equivalent or parallel to his own deductions, Truog (65) proposed a new theory. He wrote as follows:

> The supply of available calcium in all forms becomes less as soils become acid, but usually there is still sufficient present to furnish that needed as direct plant food material. . . . The comparison reveals a close correspondence and hence substantiates the theory, which has been proposed, that usually the main specific injury of soil acidity is that it prevents plants, especially those with high lime requirement and relatively weak feeding powers, from getting the lime from the soil at a sufficiently rapid rate to meet their needs. . . . The expression " lime requirement " of a plant refers to the actual lime needs of the plant itself, especially as to the need and rate at which lime must be secured from the soil by the plant for normal growth.

However, in this and in a succeeding publication with Meacham (66), Truog carried the reasoning further into the physiology of the plant and states that

> The main specific harmful influence of soil acidity on certain plants is due . . . to its influences in preventing these plants from getting, at a sufficiently rapid rate, the calcium as carbonate or bicarbonate which is needed to neutralize and precipitate certain acids in the plants themselves. . . . In the life processes of plants, acids are formed, some of which are probably simply by-products. Lime and other bases are needed to neutralize these acids. . . . Unquestionably, in many cases, soil acidity, by limiting the supply of lime available for plants, effects the acidity of the juice or protoplasm of these plants.

He concludes that a sufficient supply of carbonate or bicarbonate of lime is essential as a regulatory component of the plant juice in maintaining the optimum hydrogen-ion concentration of the plant sap.

Sharp and Hoagland (53) are of the opinion that, even with the presence of suspended soil particles, "Soil acidity should not be set apart and considered as a phenomenon unrelated to the ordinary concepts of acidity," and from their hydrogen-electrode studies they conclude, "Soil acidity is due to the presence of an excess of hydrogen ions in the soil solution."

Conner (13) advanced the procedure, "in which the catalysis of ethyl acetate is taken as a measure of the soluble soil acidity." Conner concluded that the neutralization of acid silicates is a chemical function, rather than a physical one, because of the evolution of heat incident to the neutralization. He likewise established a parallel between the extent of hydration of clay and the amount of acidity found. Conner made the further interesting observation, later confirmed as an observation upon plant growth by Brooks, as well as by Hartwell and by Mirasol, that acid phosphate reduced the injurious effects of soil acidity.

Truog (64), in offering a method for the quantitative determination of the causes responsible for soil acidity, states that "The insoluble nature of the soil acids must be clearly recognized in an attempt to devise satisfactory methods for detecting and determining them," and that it is "a bold assumption" to assume "that the acids in all soils are of the same strength." He accordingly attempts to differentiate between the "active" and "inactive" or "latent" acidity in determining the total. Treatments with $Ba(OH)_2$ for one minute and then carbonation of the residual hydroxid by CO_2, followed by evaporation and CO_2-liberation determination, is the procedure employed to determine the active acidity, while the total acidity is determined in the same way except that the contact of $Ba(OH)_2$ and soil

is maintained at boiling temperature for thirty minutes. The "latent" or "inactive" acidity is determined by difference. Truog thinks "that the seriousness of a soil's acidity and the urgency of the need of lime is not indicated by the total active acidity alone. It is necessary to also consider the avidity of the active acid." In another part of the same article Truog states, "From other data, although inconclusive, it appears that, in upland soils, the active acidity is due largely to acid silicates and the latent acidity to a peculiar condition of kaolinites and allied compounds." In his summary, Truog states, "Soil acidity is due to true acids and not to selective ion adsorption by colloids."

In using identical treatments as to additions, but different periods of contact at widely different temperatures, Truog thus arrives at the conclusion that the greater reaction effected at the higher temperature over the longer period of contact is a measure of acidity different from that of the shorter period of contact. However, in the previously cited work of Wheeler and that of MacIntire, Willis, and Hardy, and of others, the principle of continuous reaction was established and later independently confirmed by means of an entirely different technic in the hands of Bouyoucos.

In the two cited papers from the Tennessee Agricultural Experiment Station it was shown that "rutile, opal, silt, red clay, soapstone, kaolinite, serpentine, aluminum silicate, and oxygen-combusticated residues of loam previously excessively treated (as measured by the Veitch procedure) with $CaCO_3$ and $MgCO_3$ continued to effect evolutions of CO_2 from further moist contact with alkali-earth carbonates. This continued reaction was noted after progressive periods of 14, 28, 56, 78, 133, and, in the three instances so tried, also up to 473 days, even tho the siliceous and titanic materials were first heated at white heat for 16 hours. It is hardly conceivable that the residual acid-reacting substances could be other than some form of siliceous combination.

Truog (63) offered a further dissertation in which he endeavored to invalidate the previously mentioned work of Cameron and also that of Harris, who ascribed acidity indications as being induced by selective removal of basic ions. Truog believes selective ionic absorption to be "questionable." He further believes, in disagreeing with the reverse contentions and evidence of others, that "When conditions are properly controlled, . . . the reactions due to soil acidity take place according to chemical equivalence. . . ." In contravention, it might be pointed out that carbonated water solutions of $CaCO_3$

and $MgCO_3$, in excessive amounts, vary very markedly both in active mass and in the extent to which they undergo decomposition and fixation with thoro contact and under field conditions, as was previously pointed out in the cited work of the Tennessee station.

Bouyoucos (9) ingeniously adapted the lowering of the freezing point of neutral salt solutions to a study of soil acidity. His investigations apparently justify the conclusion:

> The presence of soluble acid, or acid salts, in the mineral soils under favorable natural conditions is only temporary, if ever present, and never permanent. . . . The acidity of mineral soils appears to be due almost entirely to acid alumino-silicates, silicic acid and silica and (that) the mineral soils rarely, if ever, contain permanently free soluble acids. . . . The acidity or lime requirement of the soils might be ascribed almost entirely to insoluble hydrated silicic acid, acid alumino-silicates, silica and organic insoluble substances, in the case of mineral soils; and to organic soluble acids and humus substances and organic insoluble acids and humus substances in the case of peats and mucks. . . . There appears, then, to be practically no active acidity in the mineral soils, but only negative.

Bouyoucos thus differentiates, as do many others, between rock derived soils and peats and mucks.

Rice (50) used thirty-three soils in studies upon hydrogen-ion intensities thru the use of soluble neutral salts and came to the conclusion that "Acid soils rarely contain water soluble acids; but one case of mineral soil and one of muck soil was found that did yield acid to water."

Ames and Schollenberger (2) published an exhaustive resumé of the outstanding researches and viewpoints relative to soil acidity and its causes. They also offered comparative studies upon the Veitch, Hopkins, Hutchinson and McLennan, MacIntire, and their own "vacuum" method, which they found to give results higher than those obtained by the other methods. Their method is based upon the determination of CO_2 evolved from soil and $CaCO_3$ when boiling with reduced pressure, in order to minimize the disintegrating effect of heat upon organic matter. Among some of the viewpoints entertained by these workers we may quote: ". . . soil acidity, as the term is applied to the usual soil of mineral origin, is a negative property." "The phenomena of soil acidity are thus but symptoms of a condition—the lack of basic material—which is to say, poverty in basic calcium." And discussing the occurrence and nature of alumino-silicic and silicic acids, "A soil may thus give an alkaline extract and still possess considerable power to combine with bases." With this conception in mind, lime requirement is defined as a "soil's capacity for combina-

tion with basic calcium," with differentiation between laboratory measurement and the practical problem of "optimum effects upon crop growth." After a summation of the various concepts they conclude, "The theory of the existence of silicic or alumino-silicic acids in the soil would serve as a complete explanation for all the observed phenomena; the conception is simple and is supported by analogy with better known reactions, which is as much as can be said for any of the theories which have been offered." As a practical application they are of the opinion that "There is no evidence that any of the methods tested furnished reliable indications as to the optimum rate of application for field practice."

Rice and Osugi (51) utilized the extent of inversion of cane sugar induced by contact with soil suspensions as an index to acidity. They found that inversion of cane sugar was induced by a soil-contact treatment even tho "the digestion extracts were found to be alkaline." Further, "There is no doubt, then, that a soil may contain an acid and, at the same time, enough base to neutralize this acid without this neutralization ever taking place," thus offering a possible explanation of the continued occurrence of $CaCO_3$ in intimate contact with soil in the field, altho equivalent $MgCO_3$ treatments had long before disappeared, as had been previously mentioned. By their ingenious method of approach, these workers established the fact that relatively "insoluble silicic acid and adsorbed acids, as well as soluble acid, may invert cane sugar," and in several ways demonstrated "that the inverting activity of soils is chiefly a property of the insoluble part." These findings are well correlated with the Tennessee station findings and conclusions that free silicic acid, as represented by quartz, may, in mass, effect extensive decomposition of alkali-earth carbonates and further that acid silicates, relatively insoluble, have an extensive decomposing action upon alkali-earth carbonates.

Stephenson (55), in a study of "soil acidity methods" involving the Hopkins, Veitch, Jones, MacIntire, Truog, and Tacke methods of procedure, concludes, "The activity of soil acids varies greatly as measured by the rate of evolution of carbon dioxide. The more reactive acids react at once. The less reactive only after long contact and thorough mixing of soil and carbonate and more complete removal of carbon dioxide liberated."

Plummer (49) studied the reaction of a number of North Carolina soils by the electrometric method of determining hydrogen-ion concentration. He states, "It would appear that, with the excessive rainfall of this region, an accumulation of soluble acids in soils would

be almost impossible." He found the reaction of the free and soil-film water to be identical, but of varying intensity. The concentration of the film-water was greater than that found in suspensions, in both instances, of excess of hydrogen-ion in the untreated soils and OH-ion for the $CaCO_3$- and $MgCO_3$-treated soils. He found acid phosphate to be negative in its effect, while $NaNO_3$ treatments augmented OH-ion concentration. Potassium sulfate increased H-ion concentration, but not to the extent brought about by ammonium sulfate.

Hoagland and Sharp (27) are of the opinion that soil acidity "has a definite and precise meaning; namely, the condition of the soil in which its aqueous solution contains H-ion in excess of OH-ion"; and that "these H-ion concentrations may be definitely determined by measurements with the hydrogen electrode." Furthermore, they are of the opinion that, "lime requirement, insofar as it is related to soil acidity, would consist of the amount of lime necessary to bring the acid soil to the neutral point as ascertained by the above mentioned procedure." "Such a lime requirement implies that the dissolved and total undissolved soil acids have been neutralized." However, "The reaction is so prolonged either by rate of solution of the soil acid, or their slow diffusion through the soil particles, that the point of neutrality may not seem easy to establish and maintain permanently." Thus, "An apparent equilibrium may be disrupted, owing to the solution and diffusion of the soil acid." Altho, as cited in this paper, treatments of some soils with carbonated water will extract and yield $CaCO_3$ leachings by hydrolysis and carbonation, thereby enhancing the $CaCO_3$ decomposing power of the more acid residue of soils, these workers conclude—"The hydrogen-ion concentration of suspensions of acid soils is not markedly effected by increasing the content of carbon dioxide up to ten percent."

As seemingly in contradiction to this conclusion, Noyes and Yoder (45) found that, "Carbon dioxide added to cropped soil (not suspensions), treated with lime alone, or lime and fertilizer, increased its acidity," as indicated by the Hopkins method.

Gillespie and Hurst (21), in continuing their hydrogen-ion concentration studies upon the solution phase of soil acidity, concluded that an "examination of a large number of soils from northern Maine showed an excellent correlation between the hydrogen-ion concentration and occurrence of common potato scab."

Hartwell and Pember (26) studied the reason for improvement in growth of barley induced by lime, as contrasted with "the very little influence upon the growth of rye." They found that while the two

crops reacted in close parallel to acidified nutrient solutions, they varied in their growth in acid soils and also in the aqueous extract from the same soils. These workers concluded that the presence of aluminum in true solution was the cause of toxicity to the barley. Elimination of soluble aluminum was brought about by addition of phosphates, as well as by lime. As a practical application of their findings they conclude: "The results indicate that the practical advantage of phosphating and liming may often prove to be due to the precipitation of active aluminum, quite as much as to phosphorus as a nutrient, or lime as a reducer of acidity."

White (74) used the Veitch procedure as an index to changes induced by the incorporation of stable manure and leguminous and non-leguminous green manures. He found that acidity, as registered by the procedure, was decreased initially, but later an augmented acidity was found, due in the main, it appeared, to nitrification.

Howard (30) advanced a procedure based upon the evaporation of soil and of excess of ammonia at the temperature of boiling water and the determination of the residual ammonia, the fixation of which he observed was independent of the amount added, time of contact, and temperature of evaporation. By this worker, "It is believed that the ammonia retained is held chemically by a neutralization of either free acids, acid organic compounds or acid salts, while physical absorption is largely prevented."

Conner (14) studied the changes in "soil acidity as effected by moisture conditions of the soils," using the Veitch, Jones, and Conner methods to record changes. The acidity of the half-saturated soils was greater than that of the one-fourth saturated, both being greater than that of the original soil. Conner is of the opinion that "Primarily, soil acidity is due to an excess of acid reacting compounds, or in other words, to a deficiency of bases. This deficiency of bases is caused to a large extent by the leaching of calcium and magnesium in the drainage water." He stresses the potential acidity of silicic acid, when in a hydrated state of combination with aluminum.

Sharp and Hoagland (54), in repeating some of the work of Rice and Osugi, confirmed the fact that SiO_2 would affect the inversion of cane sugar and recorded the acidity of the quartz as measured by the hydrogen-ion determination. They further contended, as opposed to Rice, that the water extracts of the acid soils were acid and that such extractions effected inversion of cane sugar; the extent of such reversion by soils being, in a measure, a function of the intensity of the acidity registered by the H-ion determination.

Stephenson (56), in studying the "activity of soil acids" by the use of the Tacke method over various periods of time, confirms previous observations to the effect that the reaction between carbonate of lime and soil is progressive and cumulative. To the presence of acid silicates and silicic anhydride, formed during the process of soil formation, he attributes the fact that "Mineral soil may have a comparatively large reserve of slowly reactive acid . . . capable of a more or less indefinite but continuous decomposition of carbonate." He further points to the fact that any mineral acid, such as sulfuric, engendered from the oxidation of inorganic or organic sulfur compounds, or nitric acid, engendered thru nitrification, are quickly neutralized and eliminated by leaching. Concerning organic acids, he is of the opinion that "the general indication is, therefore, that organic matter is not likely to produce a harmful soil acidity."

Howard (31), in studying the basicity increase incident to the use of nitrate of soda, as contrasted to the enhanced acidity subsequent to the use of sulfur of ammonia, concludes:

> The acidity of a soil caused by long continued use of ammonium sulphate is a result in the change of the ratio of acids to bases. The position normally occupied by the stronger bases, such as calcium and magnesium, has been taken by weaker bases, such as iron and aluminum. The neutrality of the soil solution can no longer be maintained, since salts of these weak bases dissociate. Free acid, resulting from this dissociation, is accompanied by a definite concentration of hydrogen-ions.

From an investigation of the "reduction potentials of bacterial cultures and waterlogged soils" Gillespie (20) suggested the possibility "that 'sourness' of soils includes something beyond acidity and (that) the residual unfavorable quality may be a high intensity of reduction."

In testing the reactions of a number of plats under numerous conditions, Blair and Prince (8) employed the Veitch procedure as a quantitative index, while simultaneously observing the intensity of the acidity by means of colorimetric hydrogen-ion determinations. The relationships between initial quantity and intensity coefficients of untreated soil and those recorded subsequent to half-ton, 1-ton, and 2-ton applications of limestone and dolomite were such as to lead to the conclusion that, "for the samples tested there appears to be a fairly close correlation between the hydrogen-ion concentration of the soil extract and the lime requirement as determined by the Veitch method."

Martin (42) found in a study of the control of potato scab through the use of flowers of sulfur, thereby decreasing basicity or increasing

acidity, that the hydrogen-ion concentrations of water extracts were increased by sulfur treatments and that such an increase depressed the injury due to scab. Martin found a correlation between the initial H-ion concentration and the residual as influenced in measurable degree by the varying amounts of sulfur treatment. He was of the opinion that it is both feasible and economical to regulate the sulfur treatments by means of an initial H-ion determination.

Mirasol (43) studied the effect of soluble aluminum as a factor in soil acidity, using the modified KNO_3 procedure of Hopkins as a measure of the formation of aluminum nitrate. He reported that "from 44–60 percent of the aluminum in the soil may be leached out by potassium nitrate and that the leaching of this amount is accompanied by a big decrease in the acidity." "The 40 or 60 percent of aluminum leached out represents these soluble compounds or active aluminum . . . equivalent to approximately 53,240 and 90,720 pounds per acre respectively." He discusses the harmful effect of excess of aluminum which may be present in the soil, as either sulfate or nitrate, and confirms the previous work wherein both acid phosphate and lime were effective in decreasing the occurrence of soluble toxic aluminum salts. Instead of applying the method upon the basis of his statement of the original conception, "that the acids (humic acids) react with the salt solution, uniting with the mineral base, forming neutral humates and liberating the mineral acid or acid salt." Mirasol concludes, "In so far as aluminum is a factor in soil acidity, the Hopkins method is the best one for soil acidity determinations."

SUMMARY.

The acidity of mucks and peats poor in alkali and alkali-earth bases can not be considered on the same basis as rock-derived soils. The organic contents of peats and mucks possess acid, or base fixing, properties. It is a mooted point whether such acidity is caused by adsorption or by true acids.

Considering rock-derived soils—

1. Altho salts of a number of organic acids have been isolated from soils, no one definite free organic acid has ever been extracted, as of record.

2. If all of the organic carbon in many soils was considered as being a constituent of a definite organic acid, the hypothetical acid so calculated would be equivalent to only a fraction of the amount of acidity determined by different methods of procedure.

3. In practice, certain salts produce a decrease of soil acidity (so-

dium nitrate, potassium nitrate, etc.), tho in the laboratory treatments during short periods followed by extractions, the reverse may be true; while the addition of certain other neutral salts produced an increase in acidity in both laboratory and field due to removal of native bases or amphoteric elements.

4. Removal, or adsorption, of dissolved bases by soils appeared to be a chemical function of acid silicates, principally alumino-silicates, the extent of whose hydration is a controlling factor in initial intensity and continuity of reaction.

5. The acidity of soils is, in the main, induced by the loss of calcic and magnesic inorganic salts, derived originally from the hydrolysis of the alkali-earth siliceous complexes, thereby increasing the acid properties or amount of acid silicates.

6. Where the base and its combined radical are added, in H_2O solutions, to soils, and in equivalence, with reference both to mass and degree of dissociation, the adsorption of basic ions may be considered as of near equivalence. But when alkali-earth carbonates ($CaCO_3$ and $MgCO_3$) are subjected to moist and intimate contact with acid soils, the active masses will vary in amount and degree of dissociation, while the precipitated product of the reactions will vary in their solubility, or tendency toward reversion thru hydrolysis and re-carbonation; hence, the difference in attaining and maintaining equilibria and the disparity in the extent of the reactions, which will vary markedly from chemical equivalence in a given time.

7. Silicic acid, in mass, will progressively hydrolyze and continue to decompose calcium and magnesium carbonate when the liberated CO_2 is removed from solution. This acid will pass from the solid to solution phase yielding H-ion concentration and is capable of effecting an inversion of cane sugar.

8. After intense alkali treatments and the removal of excess of hydrates and after intense heating, pure silica, silicates, and titanium oxid will, on the addition of H_2O, hydrolyze and act as acids towards the alkali-earth bases.

9. Many acid soils will yield aqueous extracts, alkaline to some of the common indicators, but showing H-ion concentration by electrometric or colorimetric methods.

10. The H-ion concentrations of acid soils are not generally considered as being of such intensity as to be of direct detriment to higher plant life, tho they may effect the growth of bacteria and fungi.

11. The injurious effect of acidity may be attributed, in some instances, to aluminum and other toxic salts, but, in general, more par-

ticularly to the diminished supply of available calcium from the depleted lime content of the soil, as influencing the adaptability of the media for biological development and the meagerness of the lime as plant food, or as an essential regulatory component of the plant juice.

12. The formation of organic acids and the generation of mineral acids, such as nitric, in soils may be conceded; but their occurrence within the soil seems to be of but brief duration, because of neutralization by native or applied basic materials.

13. The reactions between soils and alkali-earth carbonates are characterized by a more intense initial activity, with a continued and lesser intensity extending over a long period of time. Such variations have been attributed to different acids, of active and less active "avidity," or to the greater immediate solubility and the lesser progressive solubility of silicic acid and its acid salts.

14. An excess of basic carbonates may occur in a soil possessing slow-reacting, but potential, acidity, in the form of slowly hydrolyzing and ionizing silicic acids and their acid hydrogen salts.

15. And finally, tho not unanimously agreed, it seems to be the majority viewpoint that the laboratory determination of a soil's tendency to absorb, fix, or neutralize lime is an academic consideration, without any definitely established quantitative correlation with field practice.

Literature Cited.

1. Abbott, J. C., Conner, S. D., and Smalley, H. R. Soil acidity, nitrification, and the toxicity of soluble salts of aluminum. Purdue Univ. (Ind.) Agr. Expt. Sta. Bul. 170. 1913.
2. Ames, J. W., and Schollenberger, C. J. Liming and lime requirement of soil. Ohio Agr. Expt. Sta. Bul. 306. 1916.
3. Albert, R. Eine neue Methode zur Bestimmung der Bodenaciditat. *In* Ztschr. Angew. Chem., Bd. 22, p. 533. 1909.
4. Baumann, R. Untersuchungen über die Humussäuren. I. Geschichte der Humussäuren. *In* Mitt. K. Bayr. Moorkulturanst., Heft 3, p. 52–123. 1910.
5. Bemmelen, J. M. van. Die Absorptionsverbindungen und das Absorptionsvermöngen der Ackerede. *In* Landw. Vers. Stat., v. 35, no. 75, p. 136. 1888.
6. Bizzell, J. A., and Lyon, T. L. Estimation of the lime requirement of soils. *In* Jour. Indus. and Engin. Chem., v. 5, no. 12, p. 1011, 1012. 1913.
7. Blair, A. W., and Macy, E. J. Soil studies II: Acid soils. Fla. Agr. Expt. Sta. Bul. 93. 1908.
8. Blair, A. W., and Prince, A. L. The lime requirement of soils according to the Veitch method, compared with the hydrogen-ion concentration of the soil extract. *In* Soil Sci., v. 9, no. 4, p. 253–260. 1920.

9. BOUYOUCOS, G. J. The freezing point method as a new means of determining the nature of acidity and lime requirement of soils. Mich. Agr. Expt. Sta. Tech. Bul. 27, p. 6, 52, 56. 1916.
10. BROWN, P. E., and JOHNSON, H. W. The effect of grinding t e soil on its reaction as determined by the Veitch method. *In* Jour. Indus. and Eng'n. Chem., v. 7, no. 9, p. 776, 777. 1915.
11. CAMERON, F. K., and BELL, J. M. The mineral constituents of the soil solution. U. S. Dept. Agr., Bur. Soils Bul. 30. 1905.
12. CLARK, F. W. The constituents of the natural silicates. U. S. Geol. Surv. Bul. 588. 1914.
13. CONNER, S. D. Acid soils and effect of acid phosphate and other fertilizers upon them. *In* Jour. Indus. and Engin. Chem., v. 8, no. 1, p. 35-40. 1916.
14. ——. Soil acidity as affected by moisture conditions of the soil. *In* Jour. Agr. Research, v. 15, no. 6, p. 321-329. 1918.
15. COOK, R. C. Effect of grinding on the lime requirement of soils. *In* Soil Sci., v. 1, no. 1, p. 95. 1916.
16. COVILLE, F. V. The agricultural utilization of acid lands by means of acid-tolerant crops. U. S. Dept. Agr. Bul. 6, p. 7-12. 1913.
17. DAIKUHARA, G. Ueber saure Mineralböden. *In* Bul. Imp. Cent. Agr. Expt. Sta. Japan, v. 2, no. 1, p. 1-40. 1914.
18. FREAR, WM. Sour soils and liming. Pa. Dept. Agr. Bul. 261, p. 97. 1915.
19. GILLESPIE, L. J. The reaction of soil and measurements of hydrogen-ion concentration. *In* Jour. Wash. Acad. Sci., v. 6, no. 1, p. 7-16. 1916.
20. ——. Reduction potentials of bacterial cultures and of water-logged soils. *In* Soil Sci., v. 9, no. 4, p. 215. 1920.
21. ——, and HURST, L. A. Hydrogen-ion concentration—Soil type—Common potato scab. *In* Soil Sci., v. 6, no. 3, p. 235. 1918.
22. GREGOIRE, ACH. Contribution à l'etude de l'acidité des terres. *In* Bul. Soc. Chim. Belg., v. 26, p. 336-342; 362-375; 386-400. 1912.
23. HALES, S. *In* Proc. Royal Soc. England, 1739. *Cited by* Patten and Waggaman (48, p. 9).
24. HALLEMAN, ARNOLD F. Über die Bekalkung von steifen Kleyboden. *In* Landw. Vers. Stat., v. 41, p. 37-41. 1892.
25. HARRIS, J. E. Soil acidity. Mich. Agr. Expt. Sta. Tech. Bul. 19. 1914.
26. HARTWELL, B. L., and PEMBER, F. R. The presence of aluminum as a reason for the difference in the effect of so-called acid soil on barley and rye. *In* Soil Sci., v. 6, no. 4, p. 259-280. 1918.
27. HOAGLAND, D. R., and SHARP, L. T. Relation of carbon dioxid to soil reaction as measured by the hydrogen electrode. *In* Jour. Agr. Research, v. 12, no. 3, p. 139-148. 1918.
28. HOPKINS, C. G. Soil Fertility and Permanent Agriculture, p. 176, 628. Ginn and Co., Boston. 1910.
29. ——, KNOX, W. H., and PETTIT, J. H. A quantitative method for determining the acidity of soils. Proc. Amer. Offic. Agr. Chem., 1902. *In* U. S. Dept. Agr., Bur. Chem. Bul. 73, p. 114-119. 1903.
30. HOWARD, L. P. The relation of the lime requirements of soils to their retention of ammonia. *In* Soil Sci., v. 6, no. 6, p. 405-411. 1918.
31. ——. The relation of certain acidic to basic constituents of the soil affected by ammonium sulfate and nitrate of soda. *In* Soil Sci., v. 8, no. 4, p. 320. 1919.

32. HUTCHINSON, H. B., and MACLENNAN, K. The determination of the lime requirements of the soil. *In* Chem. News, v. 110, no. 2854, p. 61. 1914.
33. JONES, C. H. Method of determining the lime requirement of soils. Proc. Amer. Offic. Agr. Chem., 1913. *In* Jour. Assoc. Offic. Agr. Chem., v. 1, no. 1, p. 43, 44. 1915. *Abs. in* Amer. Fert., v. 39, no. 11, p. 28, 29, 1913; *also in* Chem. Abs., v. 9, no. 14, p. 1961, 1913.
34. KNISELY, A. L. Acid soils. Oreg. Agr. Expt. Sta. Bul. 90, p. 6. 1906.
35. LINT, H. CLAY. The influence of sulfur on soil acidity. *In* Jour. Indus. and Engin. Chem., v. 6, no. 9, p. 747, 748. 1914.
36. LIPMAN, J. C. Bacteriological methods for the estimation of soil acidity. Proc. Assoc. Offic. Agr. Chem., 1911. *In* U. S. Dept. Agr., Bur. Chem. Bul. 152, p. 51. 1912.
37. LOEW, O. Studies on acid soils of Porto Rico. Porto Rico Agr. Exp. Sta. Bul. 13, p. 5, 7, 23. 1913.
38. MACINTIRE, W. H. A new method for the determination of lime requirements of soils. *In* Proc. Assoc. Offic. Agr. Chem., 1914. *Abs. in* Amer. Fert., v. 41, no. 11, p. 36. 1914. *Also*. A method for the determination of the immediate lime requirements of soils. *In* Jour. Indus. and Engin. Chem., v. 7, no. 10, p. 864-867. 1914.
39. ——. Factors influencing the lime and magnesia requirements of soils. Tenn. Agr. Exp. Sta. Bul. 115, p. 41-45. 1916.
40. ——. Status of the problem of lime requirement. *In* Jour. Assoc. Offic. Agr. Chem., v. 3, no. 1, p. 144-149. 1917.
41. ——, WILLIS, L. G., and HARDY, J. I. The non-existence of magnesium carbonate in humid soils. Tenn. Agr. Expt. Sta. Bul. 107. 1914.
42. MARTIN, W. H. The relation of sulfur to soil acidity and to the control of potato scab. *In* Soil Sci., v. 9, no. 6, p. 393-408. 1920.
43. MIRASOL, JOSE JISON. Aluminum as a factor in soil acidity. *In* Soil Sci., v. 10, no. 3, p. 153, 183, 190. 1920.
44. MOULTON, C. R., and TROWBRIDGE, P. F. The estimation of the lime requirement of soils by means of the hydroxide of the alkalin earths. *In* Jour. Indus. and Engin. Chem., v. 6, no. 10, p. 835-837. 1914.
45. NOYES, H. A., and YODER, LESTER. Carbonic acid gas in relation to soil acidity changes. *In* Soil Sci., v. 5, no. 2, p. 151-161. 1918.
46. PARKER, E. G. Selective adsorption by soils. In Jour. Agr. Research, v. 1, no. 3, p. 179-188. 1913.
47. ——. Selective adsorption. *In* Jour. Indus. and Engin. Chem., v. 6, no. 10, p. 831. 1914.
48. PATTEN, H. E., and WAGGAMAN, W. H. Absorption by soils. U. S. Dept. Agr., Bur. Soils Bul. 52. 1908.
49. PLUMMER, J. K. Studies in soil reaction as indicated by the hydrogen electrode. *In* Jour. Agr. Research, v. 12, no. 1, p. 19-31. 1918.
50. RICE, FRANK E. Studies on soils—I. *In* Jour. Phys. Chem., v. 20, no. 3, p. 227. 1916.
51. ——, and OSUGI, S. The inversion of cane sugar by soils and allied substances and the nature of soil acidity. *In* Soil Sci., v. 5, no. 5, p. 333-356. 1918.
52. RUPRECHT, R. W., and MORSE, F. W. The effect of sulfate of ammonia on soil. Mass. Agr. Exp. Sta. Bul. 165, p. 89, 90. 1915.

53. SHARP, L. T., and HOAGLAND, D. R. Acidity and adsorption in soils as measured by the hydrogen electrode. *In* Jour. Agr. Research, v. 7. no. 3. p. 124. 1916.
54. ——, ——. Notes on recent work concerning acid soils. *In* Soil Sci., v. 7. no. 3, p. 197–200. 1919.
55. STEPHENSON, R. E. Soil acidity methods. *In* Soil Sci., v. 6, no. 1, p. 33–52. 1918..
56. ——. Activity of acid soils. *In* Soil Sci., v. 8, no. 1, p. 41–59. 1919.
57. STODDART, C. W. Soil acidity and its relation to lack of available phosphates. *In* Jour. Indus. and Engin. Chem., v. 1, no. 2, p. 69–74. 1909.
58. SÜCHTING, H. Eine verbesserte Methode zur Bestimmung der Acidität von Böden. *In* Ztschr. Angew. Chem., Jahrg. 21, p. 151–153. 1908.
59. SULLIVAN, E. C. The interaction between minerals and water solutions. U. S. Geol. Surv. Bul. 312, p. 8. 1907.
60. TACKE, BR. Ueber die Bestimmung der freien Humussäuren in Moorboden. *In* Chem. Ztg., v. 21, p. 174, 175. 1897.
61. TEMPLE, J. C. Nitrification in acid or non-basic soils. Ga. Agr. Expt. Sta. Bul. 103, p. 15. 1914.
62. TRUOG, E. A new test for soil acidity. Wis. Agr. Expt. Sta. Bul. 249. 1915. *Also*, Soil acidity and methods for its detection. *In* Science, n. s., v. 40, p. 246–248. 1914.
63. ——. The cause and nature of soil acidity with special regard to colloids and adsorption. *In* Jour. Phys. Chem., v. 20, no. 6, p. 457–484. 1916.
64. ——. A new apparatus for the determination of soil carbonates and new methods for the determination of soil acidity. *In* Jour. Indus. and Engin. Chem., v. 8, no. 4, p. 341. 1916.
65. ——. Soil acidity: I. Its relation to the growth of plants. *In* Soil Sci., v. 5, no. 3, p. 192, 193. 1918.
66. ——, and MEACHAM, M. R. Soil acidity: II. Its relation to the acidity of the plant juice. *In* Soil Sci., v. 7, no. 6, p. 473. 1919.
67. VEITCH, F. P. The estimation of soil acidity and requirements of soils. *In* Jour. Amer. Chem. Soc., v. 24, p. 1120. 1902.
68. ——. Discussion. Proc. Assoc. Offic. Agr. Chem., 1902. *In* U. S. Dept. Agr., Bur. Chem. Bul. 73, p. 136. 1903.
69. ——. Comparison of methods for the estimation of soil acidity. *In* Jour. Amer. Chem. Soc., v. 26, p. 637. 1904.
70. WAHNSCHAFFE, FELIX. Anleitung zur wissenschaftlichen Bodenuntersuchung, p. 158. Berlin, 1887.
71. WAY, J. T. On the power of soils to absorb moisture. In Jour. Royal Agr. Soc. England, v. 11, p. 313, 366. 1850. *Cited by* Patten and Waggaman (48).
72. WHEELER, H. J., HARTWELL, B. L., and SARGENT, C. L. Chemical methods for ascertaining the lime requirement of soils. R. I. Agr. Exp. Sta. Bul. 62. 1900. *Also in* Jour. Amer. Chem. Soc., v. 22, p. 153. 1900.
73. WHITE, J. W. The results of long continued use of ammonium sulfate upon a residual limestone soil of the Hagerstown series. *In* Pa. Agr. Expt. Sta. Ann. Rpt., 1912/1913, p. 55–102. 1914.
74. ——. Soil acidity as influenced by green manures. *In* Jour. Agr. Research, v. 13, no. 3, p. 171–197. 1918.

THE EFFECTS OF LIMING ON THE AVAILABILITY OF SOIL POTASSIUM, PHOSPHORUS, AND SULFUR.[1]

J. K. PLUMMER.[2]

THE EFFECTS OF LIMING ON SOIL POTASSIUM.

It has been known for a long time that additions of certain neutral salts to the soil bring about an exchange of bases between the added salt and those of the soil complexes.

The mechanism of this basic exchange has been the subject of some conjecture. Up until the results secured by Parker (16),[3] it was thought that the exchange of bases was one of double decomposition between the soil minerals and neutral salt, the base of the soil being partly replaced by an equivalent of that from the salt. Parker contends that this exchange is due to the absorption of the base by the soil and the formation of free acid from the anion of the salt. It is this acid which has the solvent effect on the soil bases, most important of which is potassium. When this acid is neutralized by additions of NaOH, no potash is found in solution from additions of neutral salts to the soil. However, MacIntire (12) pointed out that, when the added salt is composed of a weak anion like $CaCO_3$ and the base is absorbed, the CO_3 ion set free would probably behave in a different manner from the stronger ions of Cl, SO_4, etc. Some of the CO_2 thus formed might escape into the atmosphere, while, on the other hand, the increase in concentration of H_2CO_3 probably increases solution of the soil bases.

The addition of basic calcium and magnesium compounds to the soil is thought by some to materially affect solution of potash from the inert soil mass, so much so as to be of considerable practical value under field conditions.

LABORATORY AND POT STUDIES.

From the following review, it can be readily seen that the subject of increasing the potash supply of the soil by additions of calcium

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920. Contribution from the North Carolina Agricultural Experiment Station, West Raleigh, N. C.

[2] Formerly soil chemist, North Carolina Agricultural Experiment Station.

[3] Reference is to "Literature cited," p. 170.

and, to a lesser extent, magnesium salts has received much attention.

The earlier investigators seem to have been impressed more with possibilities of gypsum rather than with those of the basic forms of lime. This is exemplified from the following statements from Storer (18), who says "that gypsum exerts a powerful action in setting free potash, which has been absorbed and fixed by the earth, that is to say, by double silicates in the earth." This writer also goes on to say "that gypsum sets free potash to be transferred to lower layers of the soil so that roots can everywhere find a store of it."

Gaither (7) concluded from his work that little, if any, potash is made available by the action of lime on soils. He determined the potash content of wheat grown on limed and unlimed soils, showing that additions of lime depressed the potash content of the wheat. He used N/5 HNO_3 as the solvent for measuring the solution of the potash and extracted for 5 hours, the soil being Volusia silt loam, to which was applied lime, CaO, at rates from 2 to 26 tons per acre.

Bradley (1) mixed three soils with 1 percent each of CaO and $CaSO_4$, separately, and maintained 20 to 25 percent of moisture for six weeks. At the end of that time the soils were leached and increases were found in parts per million of 19.4, 26.0, and 34.1, respectively, for the blank, CaO, and $CaSO_4$ treatments. On cutting down the time of contact to 24 hours, no increase in soluble potash could be found, except from the gypsum treatment.

Morse and Curry (14) found that upon shaking orthoclase with solutions of $Ca(OH)_2$, a liberation of potash occurred, which was readily fixed when in contact with clay or kaolin. They further conclude, from field studies, that lime was of little benefit in releasing potash for the hay crop.

Fraps (5), from pot studies with applications of $CaCO_3$ and $CaSO_4$, finds no appreciable liberation of potash from either treatment, as measured by N/5 acid, or the amounts taken up by the crop.

Briggs and Breazeale (2) found that $Ca(OH)_2$ had no effect in liberating potash from orthoclase or orthoclase-bearing rock. Gypsum also reduced the solubility of the potash from orthoclase. These investigations went a step further, and found no absorption of potash by wheat seedlings grown in contact with this particular feldspar and additions of lime.

Plummer (17) grew two crops of nonleguminous plants, oats and rye, and two crops of legumes, soybeans and cowpeas, in pots out of doors, in a soil very deficient in native potash. This potash supply was augmented by additions of orthoclase, microdine, biotite and

muscovite, which represent the potash-bearing minerals of many of the soils of the States bordering the Atlantic Ocean. Calcium carbonate was added at the rates of 2 and 4 tons per acre. Determinations of potash removed by the crop were made in all cases. There was no evidence to show that potash had been forced into solution by the lime treatment when the nonlegumes were grown. The total amount of potash removed by the legume crops was greater when the carbonate had been applied, but this should not be taken to mean that the available potash had been increased. The lime had evidently made stronger plants which were capable of extracting more potash than those from the unlimed treatment.

Where these four potash-bearing minerals were treated with $Ca(HCO_3)_2$ for 96 hours, the solution filtered, and potash determined, no evidence of potash replacement could be detected. After the last crop, soybeans, had been harvested, the potash dissolved in N/5 HNO_3 was determined, with no evidence of potash replacement from additions of the carbonate.

The foregoing review represents laboratory and pot work. While this is the first step in any line of soil investigation, conditions do not always represent those of the field.

LYSIMETER AND FIELD STUDIES.

Lyon and Bizzell (10) have reported results of the first 5-year period in their lysimeter experiments. They say in part, "so far as could be ascertained from the potassium in the drainage water and the crop raised on the soil treated with lime and the soil not so treated, there was no liberation of the lime treatment."

MacIntire (12) has recently reported results of elaborate lysimeter studies with limestone, dolomite, magnesite, $CaCO_3$, $MgCO_3$, CaO, and MgO on two soil types, and concludes as follows: "With reference to these two types of soil, under the prevailing climatic conditions, . . . practical and economical applications of burnt calcareous limestone, burnt dolomitic limestone, ground calcareous limestone or ground dolomitic limestone will not effect a direct chemical liberation of native soil potassium."

Turning our attention to actual field conditions we find that water extractions of the Pennsylvania plats, as reported by Brown and MacIntire (3), show more potassium in solution from the unlimed plat than from that which received the lime treatment.

Wheeler and his associates (20) concluded that a study of the soils of Rhode Island does not indicate that lime should be considered as a vigorous potash liberant.

Effects of Liming on Soil Phosphorus.

Studies on the effects of calcium and magnesium salts, especially the carbonates, on the availability of soil phosphorus do not seem to have reached such a state of definiteness as have those on soil potassium.

POT AND LABORATORY EXPERIMENTS.

The following review of published work on this subject clearly indicates that more should be done before we can say that the practice of liming the land decreases the need of soils for applied phosphates.

Kellner et al. (9) in 1890 probably carried on the most comprehensive pot and laboratory experiments on this question up to that time. They used bottles to which had been added two soils. One of the soils came from a boggy field, high in humus, and the other was a subsoil from dry land. Quicklime was added in amounts from 0.25 to 5 percent of the soil and kept damp for two weeks, after which 0.05 percent of P_2O_5 as KH_2PO_4 was mixed in and allowed to stand for periods of one and two weeks. The amount of phosphoric acid soluble in neutral ammonium citrate was then determined. They found that the lime treatment proved very beneficial in increasing the availability or reduced fixation of the applied phosphate in the case of the high humus soil, but not in the case of the subsoil.

The two soils were of the same geologic formation, and differed only in organic matter. The authors concluded that this constituent played an important rôle. They say, however, that an application of lime ahead of one of superphosphates will in all probability have a good effect on the crop, especially if the soil is heavily charged with iron and aluminum oxids.

Very probably the lime had its greatest effect in bringing about bacterial decomposition of the humus and increasing the solubility of its phosphates rather than by actually increasing the solubility of any of the applied phosphates.

Guthrie and Cohen (8) report results of phosphate solubility experiments, using water and 1 percent citric acid as solvents. A garden soil, a stiff heavy clay, and a light sandy soil to which had been added 1 percent of freshly slaked lime were used. The lime was allowed to act for one month. The water-soluble P_2O_5 decreased during the experiment in all of the soils. Digestion with citric acid showed very little alteration in the amounts of soluble constituents during this experiment.

Ellett and Hill (4) have probably carried out the most elaborate

laboratory experiment on this subject reported up to this time. A number of Virginia soils containing high and low amounts were used. From their percolation experiments with soil, they conclude that phosphate fixation is greater on soils which contain greater quantities of iron and aluminum compounds.

The fixation of P_2O_5 in monocalcium phosphate and acid phosphate by $CaCO_3$, $MgCO_3$, $FeCO_3$ Fe_2O_3, $Fe(OH)_3$, and $Al(OH)_3$ is given in this report. It was observed in these experiments where monocalcium phosphate was used, that all the other added materials removed from solution a great deal more P_2O_5 than did the $CaCO_3$. On the other hand, where acid phosphate was used, almost as much fixation occurred from $CaCO_3$ as from Fe_2O_3, the most extensive absorbing agent used. Gerlach and Ullman claim that P_2O_5 removed in this manner is available to growing plants.

Ellett and Hill are of the opinion that the fixation of P_2O_5 takes place in the surface 6 inches of soil and that evaporation plays an important part in this process. They allowed equal evaporation, where constant amounts of soluble phosphoric acid were permitted contact with known amounts of the same basic materials, and determined the subsequent solubility of P_2O_5 in neutral ammonium citrate, N/5 hydrochloric acid, and 1 percent citric acid. The hydroxids of iron and aluminum locked up from 60 to 70 times as much of soluble phosphates as that fixed by the soil. When $CaCO_3$ was mixed with these hydroxids, the fixation was materially reduced. When $CaCO_3$ and $MgCO_3$ were used alone as fixing agents, the resulting compounds were almost completely dissolved and would have to be classed as available.

Vegetative experiments are also reported in this paper. Wheat, oats, and corn were utilized as indicators of fixation. The insoluble compounds formed from the union of acid phosphate with $CaCO_3$, $Fe(OH)_3$, and $Al(OH)_3$ were compared with acid phosphate and ground rock phosphate, in pots containing acid-washed sand. The yields of dry matter indicate that the basic phosphates, formed by the iron and aluminum compounds, are practically equal to acid phosphate for oats and corn, and they further show a high degree of availability to wheat.

The conclusions drawn from this work are that the solvents used by chemists to determine availability of phosphoric acid, when applied to compounds of fixation or reversion of phosphates by iron and aluminum compounds, do not represent in any way their true availability and can not be correlated with what the plant can or can not assimilate.

These experiments were continued in the field with no increase in available P_2O_5 according to the N/5 HNO_3 method. However, increase in crop yields was obtained by liming, indicating a possible increase in available P_2O_5 not recorded by the solvent, or the beneficial effect of a better physical and biological condition within the soil.

From the growth of a large number of different crops, in sand cultures, and using eight different phosphates, Truog (19) has found that species of plants differ largely in their ability to extract phosphorus from different sources. A number of species, such as oats and corn, are able to utilize the P_2O_5 from aluminum and iron phosphates almost to the same extent as that from acid phosphate. However, it appeared that alfalfa and the lime-loving plants could more readily utilize the phosphorus from precipitated tricalcium phosphate. Truog's explanation of this is based on the assumption of an hydrolysis of the precipitated metallic phosphate, which undoubtedly brings into solution much of the insoluble P_2O_5 and is reflected in increased crop growth. Whether additions of lime will break up the combinations supposed to be formed from the union of the hydrolysed basic phosphate and acid organic matter, or acid silicates, has not been definitely proved.

Fraps (6) conducted pot experiments with five soils, to which he applied acid phosphate both with and without carbonate of lime. Corn and sorghum were used to indicate the effects of treatments. The results of this work gave no indication that the addition of lime increased the availability of the P_2O_5 of acid phosphate.

FIELD EXPERIMENTS.

The foregoing results were obtained mainly from laboratory and pot tests. Some important data have been secured in the field and these will be discussed briefly.

Wheeler and his associates (21) have conducted extensive field experiments upon the effect produced by nine different phosphates upon a great variety of crops. The carriers of phosphoric acid include acid phosphate, bone meal, phosphate rock, and redondite (aluminum phosphate). One series of plats received lime and one series received none of this amendment. The experiments were continued for a number of years and demonstrated marked differences in the extent to which these phosphates were utilized by the different varieties of plants. These workers concluded that, instead of proving injurious in connection with the soluble phosphates, liming proved very helpful in a majority of cases, even in the case of plants not par-

ticularly in need of lime. The results seem to indicate that liming may extend the period of efficiency of the soluble phosphate in the case of a soil deficient in or devoid of $CaCO_3$ but well supplied with the oxids of iron and aluminum. The addition of lime exerted a depressing effect on the insoluble calcium phosphates. This indicates that, on soil well supplied with calcareous material, the employment of more lime might readily prove injurious, thru a depression in the availability of phosphorus.

According to Truog, Elleit and Hill, and others, the precipitated iron and aluminum phosphates show a greater degree of availability than does the freshly precipitated calcium phosphate, for a time at least, in the case of a number of species of plants. This indicates that some factor other than that introduced by the addition of lime plays an important part in effecting the availability of phosphorus.

Mooers (14) presents field results from four soil types over a period of five years. Cowpeas and wheat were grown on fortieth-acre plats, half of each plat receiving lime at the rate of 1 ton to CaO per acre. The phosphatic carriers were acid phosphate and finely ground phosphate rock. The results show that lime increased the efficiency of acid phosphate, but depressed that of the ground rock.

Effect of Liming on the Availability and Conservation of Soil Sulfur.

The data on the effects of liming on the availability of soil sulfur are very meager.

The results secured by Lyon and Bizzell (11) with the Cornell lysimeters and those of MacIntire (13) are the only available important pieces of work on this subject.

Lyon and Bizzell report the content of drainage from ten lysimeter tanks. Lime, as CaO, was added to five of these tanks at the rate of 3,000 pounds per acre. Crops were planted on four unlimed and four limed tanks. Potassium sulfate was added annually at the rate of 200 pounds per annum. One each of the limed and unlimed tanks was kept bare of vegetation thruout the experiment, which ran for four years. The uncropped and limed tank yielded an annual increase of 9 pounds of sulfur in the drainage water as compared with the unlimed tank. Where the crops were grown the limed soil yielded about 5 pounds more of sulfur than the unlimed land. The sulfate tanks yielded an annual outgo of 5.5 pounds of sulfur more than that from the tank where no lime was applied. These data bring out very clearly the increase in sulfur outgo, where lime has been added.

MacIntire has been kind enough to loan the writer tables of unpub-

lished data which he has secured from the lysimeters at the Tennessee Agricultural Experiment Station. In one set of 22 tanks MacIntire applied ferrous sulfate, iron pyrites, and flowers of sulfur with and without lime and magnesia in both light and heavy amounts. He has data also relative to the outgo of native soil sulfur as induced by CaO, MgO, $CaCO_3$, and $MgCO_3$, limestone, dolomite, and magnesite in amounts equivalent to 8, 32, and 100 tons of CaO per acre. One set of 23 lysimeters contained only the surface soil, while another set of 23 had 1 foot of clay subsoil underlying the surface soil. The experiments have been under way since July, 1914. Sulfates are determined in the drainage water at the end of each annual period. The results show that all the treatments increase the outgo of sulfates in the series receiving the 8-ton applications of burnt lime, as compared to the no-treatment tanks. The 32-ton and 100-ton treatments of CaO practically inhibit the outward movement of sulfur. No such retardation of sulfur outgo was caused by the carbonate of lime treatments. Magnesium oxid has produced the opposite effect of that caused by the quicklime. No diminution of sulfate leachings appears as a result of any of the heavy additions except in the case of burnt lime. All applications of the natural carbonates, when compared to tanks receiving no carbonate, caused an increased sulfate concentration of the leachings. The continued loss of sulfates in amounts approximating those which have transpired would effect a speedy depletion of the initial organic sulfur content, particularly from the magnesium oxid and carbonate treatments.

Summary.

This discussion has dealt with the important work touching the effects of liming on the availability of soil potassium, phosphate, and sulfur.

The more recent research, embodying laboratory extractions with weak solvents, pot studies using a variety of plants as indicators of the concentration of the soil solution in potassium and the analyses of their ash, lysimeter experiments from which the outgo of potassium has been measured, and field tests, have failed to show that basic compounds of calcium and magnesium increase, by chemical action, to any practical extent, the availability of the soil store of native potassium.

More research needs to be carried out before we can say that additions of lime will reduce the necessity of applying soluble phosphates to the soil. As measured by yields, phosphates of iron and aluminum

seem to be as available as calcium phosphates. It is very probably true that fixation of phosphatic fertilizers by colloidal absorption induced by iron and aluminum oxids is responsible for the failure of some crops to respond to phosphorus additions. Additions of lime on such soils undoubtedly flocculate some of these colloids, which gives the soil a better physical condition for plant growth.

Additions of lime, before or after applications of soluble phosphates, have greatly increased the efficiency of the phosphatic fertilizer. When insoluble calcium phosphate has been applied, it seems that applications of lime have reduced the effectiveness of the phosphate in a majority of cases.

The scant data of lysimeter experiments only, which deal with the question of sulfate availability or conservation, seem to show that liming, with small amounts of CaO, both small and large amounts of MgO, $MgCO_3$, limestone, dolomite, and magnesite, increases the solubility of native soil sulfate. Heavy applications of CaO, for a few years at least, apparently reduce this loss of sulfur from the soil.

LITERATURE CITED.

1. BRADLEY, C. E. The reaction of lime and gypsum on some Oregon soils. *In* Jour. Indus. Eng. Chem., v. 2, no. 12, p. 529–530. 1910.
2. BRIGGS, L. J., and BREAZEALE, J. F. Availability of potash in certain orthoclase-bearing soils as affected by lime or gypsum. *In* Jour. Agr. Research, v. 8, no. 1, p. 21–28. 1917.
3. BROWN, B. E., and MACINTIRE, W. H. The relation of certain water-soluble soil constituents in plats 16–24. *In* Ann. Rpt. Pa. State Col. 1910–1911, p. 105. 1912.
4. ELLETT, W. B., and HILL, H. H. Contribution to the study of phosphoric acid in soils and fertilizers. *In* Va. Agr. Expt. Sta. Rpt. 1909–1910, p. 44–65. 1911.
5. FRAPS, G. S. The effect of additions on the availability of soil potash, and the preparation of sugar humus. Texas Agr. Expt. Sta. Bul. 190. 1916.
6. ——. Effects of lime and carbonate of lime on acid phosphate. Texas Agr. Expt. Sta. Bul. 223. 1917.
7. GAITHER, E. W. The effect of lime upon the solubility of soil constituents. *In* Jour. Indus. Engin. Chem., v. 2, no. 7, p. 315, 316. 1910.
8. GUTHRIE, F. B., and COHEN, L. Note on the effect of lime upon the availability of the soil constituents. *In* Agr. Gaz. N. S. Wales, v. 18, no. 12, p. 952–956. 1907.
9. KELLNER, O., ET AL. Researches on the action of lime as a manure, with special regard to paddy fields. *In* Col. Agr. Tokyo Bul. 9, p. 1–25. 1891.
10. LYON, T. L., and BIZZELL, J. A. Calcium, magnesium, potassium, and sodium in the drainage water from limed and unlimed soil. *In* Jour. Amer. Soc. Agron., v. 8, no. 2, p. 81–87. 1916.
11. ——. The loss of sulfur in drainage water. *In* Jour. Amer. Soc. Agron., v. 8, no. 2, p. 88. 1916.

12. MacIntire, W. H. The liberation of native soil potassium induced by different calcic and magnesic materials, as measured by lysimeter leachings. *In* Soil Science, v. 8, no. 5, p. 337–394. 1919.
13. ——, Willis, L. G., and Holding, W. A. The divergent effects of lime and magnesia upon the conservation of soil sulfur. *In* Soil Science, v. 4, p. 231–235, 1917.
14. Mooers, C. A. Fertility experiments in a rotation of cowpeas and wheat. Tenn. Agr. Expt. Sta. Bul. 90. 1910.
15. Morse, Fred W., and Curry, B. E. The availability of the soil potash in clay and clay loam soils. N. H. Agr. Expt. Sta. Bul. 142, p. 49. 1909.
16. Parker, E. G. Selective adsorption by soils. *In* Jour. Agr. Research, v. 1, no. 3, p. 179–188. 1913.
17. Plummer, J. K. Availability of potash in some common soil-forming minerals. Effect of lime upon potash absorption by different crops. *In* Jour. Agr. Research, v. 14, no. 8, p. 297–315. 1918.
18. Storer, F. H. Agriculture in some of its relations with chemistry, v. 1, p. 207. Scribner's, New York. 1888.
19. Truog, E. The utilization of phosphates by agricultural crops, including a new theory regarding the feeding power of plants. Wis. Agr. Expt. Sta. Research Bul. 41. 1916.
20. Wheeler, H. J. Studies of the needs of Rhode Island soils. R. I. Agr. Expt. Sta. Bul. 130, p. 75. 1910.
21. —— and Adams, G. E. A comparison of nine different phosphates, upon limed and unlimed land, with several varieties of plants. R. I. Agr. Expt. Sta. Bul. 114. 1906.

THE FINENESS OF LIME AND LIMESTONE APPLICATION AS RELATED TO CROP PRODUCTION.[1]

William Frear.[2]

This subject, which, by the courtesy of your program committee for this meeting, I have been asked to discuss before you, had not, until about a decade ago, been a matter of at all rigorous investigation, altho such observations and experiments as were then available had led to very generally adopted recommendations for the use of care to secure a fine product in the slaking of lime and to choose fine-grained rather than the coarser marls for soil dressing, where such choice was possible.

When machinery had been developed by use of which limestone

[1] Contribution from the Pennsylvania Agricultural Experiment Station, State College, Pa. Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass, October 19, 1920.

[2] Vice director and experimental agricultural chemist, Pennsylvania Agricultural Experiment Station.

could be well pulverized, and when the need thruout the humid regions of the world for the establishing of the liming practice as an essential to the most economical crop production and to the maintenance of soil productiveness had been recognized, as well as the fitness of ground limestone as a substitute for the oxid or the hydrate of calcium, the question of the requisite fineness of these materials assumed economic importance.

ELEMENTS OF ECONOMIC IMPORTANCE.

This importance is due chiefly to the multiplier rather than to the multiplicand of production; not to one main gain from a single application, but to the tremendous values involved in the use of millions of tons of material upon millions of acres of land, over and over thru the years, and the influence of these values upon national and world prosperity.

ASPECTS OF THE LIMING ACTION.

Let us pause for a moment to consider the main elements of the liming reaction. Altho the physical system involved is in reality highly complex, we may regard the primary interchange as one between two solids, lime or limestone and an acid soil, and a liquid, the soil moisture. All experiments upon methods by which the lime requirement of an acid soil are sought to be determined show that in the presence of a solution of the full amount of calcium hydrate or calcium bicarbonate in abundance of water intimately mixed with the soil, neutralization of the latter, or, if you prefer, satisfaction of its lime-absorption capacity is, except for a small percentage of the whole, almost immediately accomplished. In other words, the affinity is strong between the alkaline calcium solution and the acid soil.

On the other hand, the rate at which water can dissolve calcium hydrate, and especially the calcium carbonate, is slow. In other words, the affinity here is relatively weak; furthermore, the quantity of these two substances required to form a saturated water solution is small, as compared with the amounts of many other substances water can dissolve. Silty loam soil may average about 18 percent of moisture thru the growing season. This represents roughly 400,000 pounds of water to 2,000,000 pounds of air-dry soil—an acre-weight to plow depth. This amount of water, when fully saturated at 60° to 70° F. could hold 6,800 pounds of calcium hydrate, but only a little more than 5 pounds of the carbonate. If the water were saturated with carbon dioxid, the calcium, whether originally presented as oxid, hydrate, or carbonate, is assumed to take the bicarbo-

nate form and, under the conditions named, the saturated soil solution would carry the equivalent of about 500 pounds of calcium carbonate. All these figures are based upon the assumption that the dissolved solids can be uniformly distributed thru the soil moisture. In brief, soil water can give up its lime to the soil much more rapidly than it can take its supply from the applied lime or limestone.

FINENESS OF LIMESTONE AS IT AFFECTS SOLUTION RATE.

The time required to dissolve a given mass of any solid substance capable of solution in a given liquid is, as you well know, dependent for one thing upon the amount of the surface it exposes to the liquid; the greater the surface, the more rapid the solution up to the limit of saturation. As the subdivision of the mass is carried forward, the aggregate surface presented by its separated particles increases in proportion as their diameter decreases. That this general rule holds good for ground limestone has been shown by White (15), Christensen (7), and Broughton (6) and his associates. It is doubtless equally true of the oxid and hydrate forms. The finer the subdivision, therefore, the shorter the time the soil moisture will require to dissolve a definite part of the applied material.

LIMESTONE POROSITY.

At this point I venture to interject a qualifying detail: Some years ago, I suggested (9, p. 175) that the porosity of the limestone would affect the amounts of surface presented by equal masses of stones equally finely subdivided, and that this difference would somewhat alter the respective rates of solution. The contrast in porosity presented by dense marble and by coral rock are well known to all who have observed these materials. What volume of pore space characterizes limestone has, however, been the subject of little study. Dr. George Otis Smith, Director of the U. S. Geological Survey, in a letter to the writer, states that the percentages of water absorption represent from 15 percent of pore space in porous rock down to negligible quantities in such marbles as those of Vermont, Georgia, and Tennessee. Bleininger and Emley (5), in determinations upon rocks used in studying lime-burning, found volumes of pore space ranging from about 7.5 percent down to less than 1 percent, with the lower figures far the more frequent. Unpublished data secured by Walter Thomas, working under the writer's direction to determine the porosity of stones representing the chief limestone formations from which Pennsylvania's commercial ground limestones are obtained,

show from 0.4 to 4.7 percent of pore space. The corresponding pore surface is unknown. The pore diameters doubtless differ greatly. Whatever surfaces they represent, for reasons which must be readily apparent the solution efficiency of these internal surfaces must be much below that of an equal external surface.

FINENESS AS IT AFFECTS DISTRIBUTION.

Finer subdivision not only increases the proportion of surface to mass, but also lends itself to more perfect mixing with the soil. A slowly soluble solid will dissolve more rapidly if kept in suspension in the solvent than if exposed to a thick layer at the bottom of a quiet body of the solvent. The stirring greatly expedites the homogeneous distribution of the solute, whereas, unaided diffusion works slowly. The study of diffusion in soils shows that, when the soils are in their ordinary field condition, the dispersion of soluble materials by this process is extremely slow and also very limited in extent (9, p. 68). For this reason, it is very important to the prompt and efficient use of lime applications, that they be intimately mixed with and uniformly distributed thru the soil masses upon which they are to act.

POT EXPERIMENTS UPON EFFECTS OF LIMESTONE FINENESS ON CROP YIELDS.

Whether the ascertained more rapid rate of solution of fine *vs.* coarse limestone particles is, after all, of sufficient influence to affect crop yields can probably best be determined by pot experiments with soils of distinctly high lime requirement and with crops of high susceptibility to lime treatment. American experiments of this kind are those of W. Thomas (13) working under the writer's direction, of J. W. White (15), and of Nicholas Kopeloff (10). Those of Thomas and Frear and of White were made on the same highly acid, silty clay loam soil; those of Kopeloff upon four acid soils from widely separated localities, and of sandy loam and silty loam textures. Thomas and Frear cropped with medium red clover, Kopeloff with crimson clover, and White with nine different crops in succession, some of these very susceptible to lime influence, two relatively indifferent. The duration of Kopeloff's cropping was not stated; that of Thomas and Frear was 8.5 months; that of White, nearly three years.

The fineness of limestone represented in Kopeloff's work ranged from that which passed a 20-mesh but not a 40-mesh sieve to that which passed a 200-mesh; in Thomas and Frear's work, the lower limit was the same as in Kopeloff's study, but the material that passed

a 100-mesh sieve was not graded, while, in White's work, the coarsest material passed an 8-mesh but not a 12-mesh sieve, and the finest passed a 100-mesh sieve. That is, as to range of fineness, these pot tests included probably the finest material open to practical use, but not the coarsest. The crop yields, taking the highest from a limestone treatment as 100, as they appeared for the single crops from the first two of these experiments, were:

TABLE 1.—*Relative crop yields from soil limed with limestone of varying fineness.*

Material used in liming.	Thomas and Frear.	Kopeloff.			
		Norfolk sandy loam.	Wooster silt loam.	Carrington silt loam.	Cumberland silt loam.
Check	0	70	24	70	38
Limestone:					
20–40 mesh	12	80	88	90	50
40–60 mesh	58				
60–80 mesh	76	95	89	87	93
80–100 mesh	95				
100–200 mesh	100	92	100	92	95
200+ mesh		100	96	100	100
Lime		110	95	108	80

Grouping the results obtained by White by years rather than using the data separately for single crops, and taking as 100 the increases over checks obtained by 100-mesh limestone, we have the data shown in Table 2:

TABLE 2.—*Increases over checks obtained from the use of limestone of varying degrees of fineness, the increase over check obtained from the use of 100-mesh limestone being taken as 100.*

Material used in liming.	First year, red clover, Canada field peas, sweet clover.	Second year, wheat, soybeans, hairy vetch.	Third year, crimson clover, Hungarian millet, lettuce.
Limestone:			
8–12 mesh	13	5	9
20–40 mesh	20	32	36
60–80 mesh	61	65	87
100 mesh	100	100	100
CaO	111	125	110

The data from the three experiments show a general tendency for the first yields after application to be superior for burnt lime as compared with limestone fine enough to pass a 100-mesh sieve, and for the yield to increase in a general way with the higher fineness of the limestone used. The limestone used by Kopeloff in a fineness of 20–40 mesh was, however, much more influential upon production

than that of the same diameter used by the others named. In White's pot experiments the 8–12 mesh stone had a slight effect in each of three years. It deserves note that, owing to the more perfect mixing than is usually obtainable for field applications, to the maintenance of optimum moisture, and to exposure to greenhouse temperatures during the winter months, the potted soils were undoubtedly more active during the periods of the respective tests than are field soils. In other words, the effects were doubtless produced in the pots in much less time than would be required to obtain these effects under field conditions. In the third year of White's experiment it is worth noting that, despite the use of different species of crop plants during the several years of the test, the order of yield in relation to fineness of the limestone was practically unchanged from that of the first year. The substantial gains from the use of 100-mesh over 8-mesh for the several crops grown by White are shown by the following ratios in which the yield of air-dry weight (green weight in the case of lettuce) with 8-mesh is stated as 1, the second figure of each ratio being the proportional yield with 100-mesh stone:

Red clover	1 : 3	Hairy vetch	1 : 2.7
Canada field peas	1 : 1.7	Crimson clover	1 : 1.5
Sweet clover	1 : 2.6	Hungarian millet	1 : 1.1
Wheat	1 : 1.2	Lettuce	1 : 8.0
Soybeans	1 : 2.0		

In White's, as in Kopeloff's, studies, crimson clover shows 70 percent as high a yield with 20-mesh stone as with 100-mesh; that is, the more favorable standing shown for the coarser grade may be characteristic of some plant species, but not of others.

FIELD EXPERIMENTS ON INFLUENCE OF FINENESS UPON CROP YIELDS.

Field experiments in which limestone of definite grade as to fineness has been applied are few in number. Ames and Schollenberger (1) report some interesting studies upon a soil distinctly acid (requirement, 5,750 lbs. carbonate by vacuum method). The crop results obtained up to the time of the report are stated proportionally to that given by nonmagnesian limestone passing an 80-mesh sieve (Table 3).

The crop differences up to that time are clearly not decisive.

Thorne (14) relates the crop results of applications of coarse screenings (all passing ¼-in. mesh), of a finer, highly calcareous stone (all passing a 1/10-in. mesh; 35 to 45 percent, of a 1/100-in. mesh) and of a hydrated lime. Of these dressings (made in addition to a

TABLE 3.—*Crop results obtained from the use of limestone of varying fineness, those from limestone of less than 1/80 inch diameter taken as 100.*

Material used in liming.	Soybean hay.	Wheat (grain and straw).	Clover hay.
Burned lime	106	114	97
Limestone:			
Less than 1/80	100	100	100
1/20 to 1/80	102	98	91
1/8 to 1/20	99	104	86
1/3 to 1/8	97	96	100
Coarse screenings[a]	109	101	86
Check	97	92	73

[a] Mechanical composition, percent: coarser than 1/3-mesh, 5; 1/3 to 1/8 37; 1/8 to 1/20, 27; 1/20 to 1/80, 19; finer than 1/80, 12.

"basic dressing" of farm manure and acid phosphate), those of the limestones were in contrasted amounts of 2 and 4 tons each; the hydate, 1.5 tons. The money values of crop increases, cost of liming, and net value of increases from corn, oats, wheat, and red clover hay in the course of a single rotation are stated in Table 4.

TABLE 4.—*Value of crop increases obtained from the use of various forms of lime.*

Material used in liming.	Total value of crop increase.	Cost of liming.	Net value of increase.
Screenings, 2 tons	$15.78	$7.50	$8.28
Screenings, 4 tons	23.60	15.00	8.60
Fine stone, 2 tons	24.16	12.0c	12.16
Fine stone, 4 tons	33.38	24.00	9.38
Hydrated lime, 1.5 tons	28.52	16.50	12.02

The lime requirement of the soil at the time of the liming is not stated. The superior crop yields from the finer material stand clearly forth.

Barker and Collison (3), judging from analogy with ground bone, comparisons between hydrated lime and limestone of rather indefinitely ascertained fineness, and the stand of alfalfa on various fields, reached the safe conclusion that if enongh 10-mesh limestone (including all associated fine material) is used to last for three years it will, without question, give fully as good results the first year as a somewhat smaller amount of extremely fine material.

Various other studies, more general in character than those above mentioned, have led to expressions of judgment in favor of the productive effects of limestone of superior fineness of subdivision, but I will not give detailed attention to them in this connection.

FINENESS OF LIMESTONE AS IT AFFECTS SOIL CONDITIONS.

Certain related studies of soil condition following liming have been made by White, Kopeloff, and Ames and Schollenberger in connection with the crop production results already given. These relate to the rate of decomposition of the applied carbonate, the degree of acidity correction, and, in several instances, to the correlated activity of soil organisms.

White found at the end of his 3-year pot tests that of the carbonate dressings initially applied, there remained in carbonate combination, of the 8-mesh stone, 85 percent; of the 20-mesh, 57 percent; of the 60-mesh, 19 percent; and of the 100-mesh, 8 percent.

Ames and Schollenberger found residual as carbonates after 16 to 23 months in the field soils to which nonmagnesian stone had been applied in different degrees of fineness: Of that which passed an 80-mesh sieve, 58 percent; 20- to 80-mesh, 48 percent; 8- to 20-mesh, 77 percent; 3- to 8-mesh, 84 percent; coarse screenings, 103 percent.

Stewart and Wyatt (12), in a comparison which included both magnesian and nonmagnesian stone applied in various combinations and in degrees of fineness severally expressed in the rather indefinite terms "$\frac{1}{4}$ inch down," "$\frac{1}{4}$ to $\frac{1}{10}$ inch," "$\frac{1}{10}$ inch down," and "$\frac{1}{50}$ inch down," found a larger proportion of carbonates residual from the group "$\frac{1}{4}$ to $\frac{1}{10}$ inch" than from the others, and least from the group "$\frac{1}{50}$ inch down." These relations were found true alike where light, medium and heavy applications (severally at the rate of 500, 1,000, and 2,000 pounds a year) of the respective groups as to fineness were compared. The experiment had run for four years, with two applications to each plat during that time. It is much to be wished that in the continuance of their work, these investigators may make such mechanical analyses as will enable us to compare more closely as to fineness the different limestones used.

Related studies were made also as to the correction of acidity effected by the respective limestone applications. White found the correction by burned lime and 100-mesh stone complete at the end of the first year; by 60-mesh stone, seven-eighths complete at the end of the first year and entirely complete the next year; by 20-mesh stone, one-half, five-sixths, and entirely at the end of the first, second, and third years, respectively; and by 8-mesh stone, one-seventh at the end of the first year and only two-sevenths at the end of the third year. Where the finest stone was used, acidity had reappeared in slight degree at the end of the third year.

Kopeloff found (Veitch method) at the end of his study, the acid-

ity had decreased four-fifths with stone finer than 100-mesh; two-thirds with 60- to 80-mesh; and one-third with 20- to 40-mesh.

Stewart and Wyatt, using the Hopkins method for acidity, found in the case of several applications of limestone, no characteristic difference in acidity correction between the several fineness grades, whether with light, medium, or heavy applications; tho the acidity decrease was greater in each instance as the amount of limestone applied increased. This finding of efficiency for the coarse stone must be regarded as exceptional.

The last mentioned investigators attempted to calculate, from the amount of carbonate decomposed and of acidity corrected, the amount of limestone lost from the soil. But it is not safe to assume that calcium, which has parted from its carbon dioxid to assume other states of combination in the soil, has wholly lost its acidity corrective value in the exchange; especially should this assumption be avoided when the total application considerably exceeds the lime requirement at the time of application.

May I again digress to remark upon the commendation occasionally appearing in lime literature for "durability" of the stone in the soil? Its economic value while "durable" is equal to that of the celebrated "single talent buried in a napkin." Thus durably buried it is losing interest at a compound rate. Serviceability, not durability, is what is required. Limestone does no work until its decomposition occurs.

OBSERVATIONS FROM NATURE.

Observation of natural soil and rock formations suggest that coarse fragments of calcium carbonate, whether amorphous, crystalline, or organized in the form of molluscan shells, do not always dissolve rapidly in the earth. Fossils in sandy or shaly rocks frequently show replacement of lime by other elements, but not always, even in the absence of a surrounding mass of calcareous material. We have in Pennsylvania, near the junction between the Chemung and the overlying Catskill formations, a tough rock of characteristic exposure known as the Burlington limestone. It carries from 40 to 90 percent, but usually only a little over 60 percent, of calcium carbonate in the form of small shells embedded in a clayey matrix. When it is burned, the thin white shells stand out distinctly from the deep red of the burned matrix. The adjacent rock materials are not distinctly calcareous.

Bernard (4) found, in a highly calcareous soil of the Jurassic region of France, deposits of coarse limestone gravel imbedded in clay

low in lime. Such soils did not, like other soils of like lime richness due to fine particles of the carbonate, produce chlorosis of the vine so common in that region. De Angelis (2) has recently made a like observation.

Limestones usually break up very slowly to form soil and, at the surface of contact with the overlying material, commonly form a marly residue, which, in turn, becomes new soil. But Noyes (11) has recently noted in a distinctly acid subsoil, adjacent to the underlying limestone from which it was formed, fragments of residual limestone ranging in size from that of a wheat kernel to others four-fifths of an inch in diameter.

FATE OF COARSE PARTICLES IN AN ALKALINE SOIL.

Plats 34, of the General Fertilizer Series of the Pennsylvania Agricultural Experiment Station, have been biennially dressed, since about 1881, with limestone at the rate of 4,000 pounds to the acre. Until 1909, these applications consisted of screenings; since then, of ground limestone practically free from particles that were coarser than 60- to 80-mesh. The screenings used in 1908, which probably typified fairly the material used in earlier years, carried 24 percent of particles that would not pass a $\frac{2}{25}$ sieve, and 55 percent that would not pass a 50-mesh sieve. In November, 1914, about six and a half years after the last coarse application, Walter Thomas, of my laboratory, sampled at my request the surface soil of the plats Nos. 34 on the four tiers of the experimental tract. Samples were taken by means of a trowel, at fifteen symmetrically located points on each plat. The samples were air-dried, composited, quartered down, screened first through a 3-m.m. round-hole sieve, and then through a ½-m.m. sieve. These "coarse" and "medium" fractions showed numerous particles of limestone. Determinations of carbon dioxid in this residual limestone showed 42.4 to 42.5 percent, corresponding to a limestone of about 96.5 percent purity. The coarse and medium fractions contained carbonates equivalent, on the acre 7-inch base, to the following amounts:

	Pounds
Tier I	3,869
Tier II	4,405
Tier III	6,639
Tier IV	6,050

Some of the limestone particles were picked out, washed, and photographed. The color was the fresh blue of the original Trenton stone

free from iron stain. The sharpness of angles is obvious in the photograph, which is enlarged several diameters to bring out clearly this character (fig. 3).

If, during their stay in the soil, none of the coarse particles were translocated to a deeper layer or disrupted by frost, these coarse residues represent the applications of not less than four to six years, and a duration of stay in the soil of not less than ten to twelve years before the sampling. The associated fine soil is, however, highly alkaline

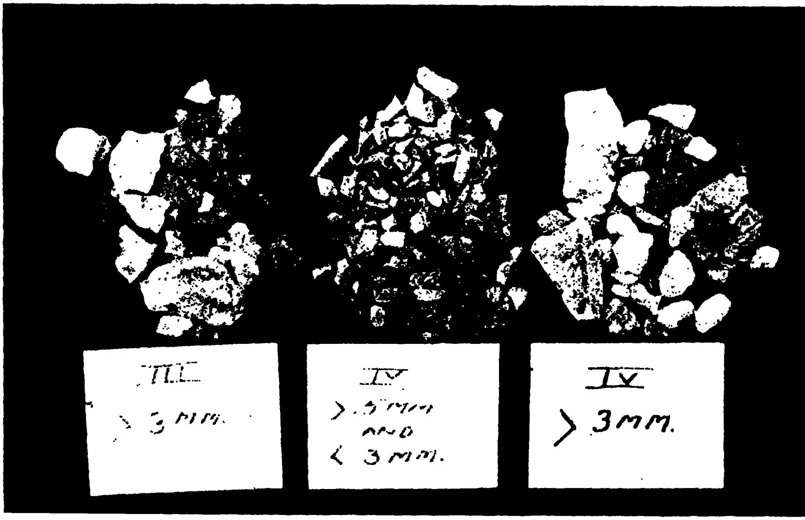


Fig. 3. Residues, years old, from coarse limestone applications on Plat 34 of the general fertilizer series, Pennsylvania Agricultural Experiment Station.

with fine particles of limestone, and more highly protective of the coarser particles against solution than would be the environment of an acid soil.

THEORY AS TO LIMING PRACTICE.

Teachers and investigators have taken two opposite views regarding the value of coarse limestone. One group emphasizes the importance of fineness of particle; the other advises abundant application of material, even tho a considerable proportion of it be quite coarse. The theory of the latter group is that with the coarse material there is enough "fines" to effect an immediate and rapid crop increase, and that, the soil acidity being corrected by these "fines," the later de-

mands can be well supplied by the more slowly soluble coarse particles. The cost of application is held to be less a unit weight when the amount is large, and an equal application of fine material, it is urged, would tend to increase lime loss in drainage water. Admittedly there is some truth in these views; how much, is the question.

So long as the fine material makes and keeps the soil moisture saturated with the carbonate, little can dissolve from the relatively small surfaces of the coarse material. The slow rate of decomposition of the larger particles in the presence of an excess of fines has just been shown. White's experiments show that particles averaging about 10-mesh, even when no fines were present, decomposed only one-fourth in a highly acid, potted soil intensively cropped for three years, doubtless representing twice as long a period under field conditions.

FINENESS OF AGRICULTURAL LIMESTONE IN CURRENT USE.

It is now in place to note that the description of the fineness of a limestone solely by reference to the finest screen thru which all of it will pass is not satisfactorily definite. Different machines and different stones produce very considerably different powders even tho the coarsest components of these powders may have approximately the same diameters. This fact is well illustrated by the percentage data secured by the Pennsylvania Department of Agriculture in the examination of commercial ground limestones during 1916, 1918, and 1919, as shown in Table 5.

TABLE 5.—*Percentage of particles of various sizes in samples of commercial limestone.*

Year and number of samples.	Coarser than 10-mesh.	10- to 50-mesh.	50- to 100-mesh.	Finer than 100-mesh.
Average for all brands:				
1916 (17)	0.9	17.5	11.9	69.7
1918 (11)	0	13.6	10.2	76.2
1919 (14)	0	15.8	11.4	72.8
Coarser brands:				
1916 (2)	2.9	55.1	12.0	30.0
1918 (2)	0	50.0	14.5	35.5

The coarser brands cost the buyer about as much as those of average fineness.

Out of nineteen samples, most of them farm-ground, recently analyzed in my laboratory, two contained over 80 percent of 100-mesh material; three, more than 50 percent. The percentages of material that passed a 40-mesh but not a 100-mesh sieve were quite low, as a

rule. Four contained more than 50 percent coarser than 20-mesh; nine others more than 50 percent that would not pass a 40-mesh. The average for the nineteen samples showed 41 percent of material finer than 100-mesh; 11 percent, 40- to 100-mesh; 20 percent, 20- to 40-mesh; and 28 percent coarser than 20-mesh. In other words, a so-called "10-mesh" stone may be either rather coarse or predominantly fine. Concerning the costs of production of these contrasted materials we know too little.

The problem is economic, and can not be determined without including all the economic factors. The freight, hauling, and application costs are identical for the coarse and fine fractions, if the material is delivered in bulk. Fippin (8), proceeding upon the assumption that average 8-mesh stone costs at the quarry \$2.50 a ton, and the 50-mesh \$3.50; that the railroad haul is 100 miles and the wagon haul 5 miles; and finally, that 50-mesh stone is entirely available in five years, 20- to 50-mesh half available, and coarser than 20-mesh not at all available in that time, figures the relative costs of 100 pounds of available oxids in stone of 95 percent purity as \$1.20 for the coarse and \$0.846 for the finer stone. That is, of course, an approximation. Stone coarser than 20-mesh will, sooner or later, become available and is not, therefore, without some slight value. If the application of the finer fraction of the ground stone is sufficient to bring maximum crops, the net return is diminished by the additional investment in the coarse stone with added compound interest until the coarse particles come into action; and if they then fail to keep up maximum production—which is very probable—there is a further loss in crop sales and compound interest on the sales deficiencies.

The matter is of enough economic importance to justify much more carefully checked field experiments for a number of rotations with limestone of carefully ascertained fineness and composition, with a thoro cost method applied to the results.

Until such results are at hand, it is my conviction, from the facts now in hand, that, without carrying the detail to extreme refinement, we should duly emphasize the present value of the fine material and avoid all suggestion of considerable and early returns from material coarser than 40-mesh, and certainly from that coarser than 20-mesh.

LITERATURE CITED.

1. AMES, J. W., and SCHOLLENBERGER, C. J. Liming and lime requirement of soil. Ohio Agr. Expt. Sta. Bul. 306. 1916.
2. ANGELIS, D'OSSAT G. DE. *In* Staz. Sper. Agr. Ital., v. 47. p. 603–620. 1914.
3. BARKER, J. F., and COLLISON, R. Ground limestone for acid soils. N. Y. State Agr. Expt. Sta. Bul. 400. 1915.

4. BERNARD, A. Le Calcaire. 1892.
5. BLEININGER and EMLEY. The burning temperatures of limestone. *In* Trans. Amer. Ceramic Society, 1911, p. 618. 1911.
6. BROUGHTON, L. B., WILLIAMS, R. C., and FRAZER, G. S. Tests of the availability of different grades of limestone. Md. Agr. Expt. Sta. Bul. 193, p. 34. 1916.
7. CHRISTENSEN, H. R. Experiments on lime and marl. *In* Tidsskr. Planteavl., v. 25, p. 377. 1918. *Abs. in* Expt. Sta. Rec., v. 42. 1920.
8. FIPPIN, ELMER O. The use of lime on the farm. Cornell Univ. Reading Course for the Farm, Lesson 148, p. 77–79. 1919.
9. FREAR, WM. Sour soils and liming. Pa. Dept. Agr. Bul. 261, p. 175. 1915.
10. KOPELOFF, NICHOLAS. Effect of fineness of subdivision of pulverized limestone on the yield of crimson clover and the lime requirement of soils. *In* Science, n. s., v. 45, p. 363–365. 1917.
11. NOYES, J. A. *In* Jour. Assoc. Official Agr. Chem., v. 3, p. 151–153. 1917.
12. STEWART, ROBERT, and WYATT, F. A. Limestone action on acid soils. Ill. Agr. Expt. Sta. Bul. 212, p. 280. 1919.
13. THOMAS, WALTER, and FREAR, WILLIAM. Experiments to determine the influence of the fineness of subdivision and richness in magnesium carbonate of crushed limestone used for amendment of acid soils. *In* Ann. Rpt. Pa. State Col. Agr. Expt. Sta., 1912/13, p. 206–219. 1913. Also, *in* Jour. Indus. and Engin. Chem., v. 7, p. 1,041. 1915.
14. THORNE, C. E. The maintenance of soil fertility. Ohio Agr. Expt. Sta. Bul. 336, p. 607–608. 1919.
15. WHITE, J. W. The relative value of limestone of different degrees of fineness for soil improvement. Pa. Agr. Expt. Sta. Bul. 149, p. 7. 1917.

Membership Changes.

The report in the March issue showed a total membership at that time of 609. Since that time 27 new members have been added and 4 lapsed members have been reinstated, while 4 have resigned, making a net gain of 27 and a present total membership of 636. While these gains are encouraging and occasional library subscriptions are being received which help to swell the total fund available for publication, many more new members must be added if the JOURNAL is to continue thruout the year on its present scale.

percent of moisture and would, therefore, increase the nitrogen content of the soil. On the other hand, the addition of the inorganic materials would dilute the soil and lower the percentage of nitrogen.

The calculation of the exact change which should be allowed for this dilution is not easily made because of the chemical changes quickly affecting the materials applied. The oxid of lime is almost immediately converted to hydrate, this is soon converted into carbonate, at least where the light applications were made, and the carbonate in turn is slowly silicated, with loss of carbon dioxid. In a similar manner the precipitated carbonate, the ground limestone, and the ground dolomite are gradually converted into silicates. As a basis for this calculation, the writers have taken 328 grams to be the average amount of inorganic matter added by the lighter applications, the 2-ton rates. On the basis mentioned, calculations have been made with regard to the percentage content of nitrogen under the various experimental conditions. The results are given in Table 4.

TABLE 4.—*Percentages of total nitrogen in the soil of the rims at the outset of the experiments on moisture-free basis (samples taken from total soil to 8-inch depth).*

Experimental condition.	Percent.
Untreated soil	0.1109
Soil with 328 grams of calcic material	.1105
Soil with 1,312 grams of calcic material	.1093
Soil with 300 grams of manure	.1157
Soil with 750 grams of manure	.1228
Soil with 1,200 grams of manure	.1298
Soil with 328 grams of calcic material and 300 grams of manure	.1153
Soil with 328 grams of calcic material and 750 grams of manure	.1225
Soil with 1,312 grams of calcic material and 1,200 grams of manure	.1280
Soil with 1,238 grams of magnesium carbonate and 750 grams of manure	.1211

CHANGES IN THE NITROGEN CONTENT OF THE SOIL.

THE SOIL SAMPLING.

Five years from the time the soil was placed in the rims under the various experimental conditions, samples were taken from each rim for the entire, or 8-inch, depth. These samples were analyzed for total nitrogen by the unmodified Kjeldahl method, using 10-gram charges of soil for each determination. The analytical results obtained by averaging duplicate determinations and calculated to a moisture-free basis are given in Table 5.

TABLE 5.—*Nitrogen content of soil at end of 5-year period under various conditions.*

SERIES K, JAPAN CLOVER AND COWPEAS.

Rim No.	Treatment. Liming material.	Quantity per rim.	Manure.	Nitrogen on moisture-free basis.
		Grams.	*Grams.*	*Percent.*
K 1	Burnt lime	181.44		0.0996
K 2	Hydrated lime	244.24		.1008
K 3	Precipitated carbonate	323.92		.0967
K 4	Ground limestone	354.68		.0998
K 5	Ground dolomite	305.62		.1001
K 6	None			.1023
K 7	Burnt lime	181.44	300	.1016
K 8	Hydrated lime	244.24	300	.1033
K 9	Precipitated carbonate	323.92	300	.1023
K 10	Ground limestone	354.68	300	.1051
K 11	Ground dolomite	305.62	300	.1011
K 12	None		300	.1028
K 13	Burnt lime	181.44	750	.1043
K 14	Hydrated lime	244.24	750	.1031
K 15	Precipitated carbonate	323.92	750	.1036
K 16	Ground limestone	354.68	750	.1057
K 17	Ground dolomite	305.62	750	.1043
K 18	None		750	.1089
K 19	Burnt lime	725.76	1,200	.1001
K 20	Hydrated lime	976.94	1,200	.0991
K 21	Precipitated carbonate	1,295.68	1,200	.1031
K 22	Ground limestone	1,418.72	1,200	.1038
K 23	Ground dolomite	1,222.48	1,200	.1046
K 24	None		1,200	.1143
K 25	Burnt lime	725.26		.0874
K 26	Hydrated lime	976.94		.0859
K 27	Precipitated carbonate	1,295.68		.0930
K 28	Ground limestone	1,418.72		.0965
K 29	Dolomite	1,222.48		.0957
K 30	None			.1036
K 31	Magnesium carbonate	1,238.07		.0993
K 32	Magnesium carbonate	1,238.07	750	.1048
	SERIES L, NO CROP, SOIL UNDISTURBED			
L 1	Burnt lime	181.44		.0950
L 2	Hydrated lime	244.24		.0957
L 3	Precipitated carbonate	323.92		.0942
L 4	Ground limestone	354.68		.0998
L 5	Ground dolomite	305.62		.0942
L 6	None			.1031
L 7	Burnt lime	181.44	300	.0976
L 8	Hydrated lime	244.24	300	.0950
L 9	Precipitated carbonate	323.92	300	.0983
L 10	Ground limestone	354.68	300	.1043
L 11	Ground dolomite	305.62	300	.1008
L 12	None		300	.1038
L 13	Burnt lime	181.44	750	.1036
L 14	Hydrated lime	344.24	750	.1016
L 15	Precipitated carbonate	323.92	750	.1026
L 16	Ground limestone	354.68	750	.1067
L 17	Ground dolomite	305.62	750	.1087
L 18	None		750	.1059
L 19	Burnt lime	725.76	1,200	.1013
L 20	Hydrated lime	976.94	1,200	.1026
L 21	Precipitated carbonate	1,295.68	1,200	.1048

TABLE 5 (continued).

Rim No.	Treatment. Liming material.	Quantity per rim.	Manure.	Nitrogen on moisture-free basis.
		Grams.	*Grams.*	*Percent.*
L 22	Ground limestone	1,418.72	1,200	.1041
L 23	Ground dolomite	1,222.48	1,200	.1001
L 24	None		1,200	.1092
L 25	Burnt lime	725.26		.0889
L 26	Hydrated lime	976.94		.0856
L 27	Precipitated carbonate	1,295.68		.0912
L 28	Ground limestone	1,418.72		.0950
L 29	Dolomite	1,222.48		.0945
L 30	None			.1062
L 31	Magnesium carbonate	1,238.07		.0965
L 32	Magnesium carbonate	1,238.07	750	.1013
	SERIES M, NO CROP, SOIL STIRRED			
M 1	Burnt lime	181.44		.0976
M 2	Hydrated lime	244.24		.0935
M 3	Precipitated carbonate	323.92		.0978
M 4	Ground limestone	354.68		.0942
M 5	Ground dolomite	305.62		.1003
M 6	None			.1028
M 7	Burnt lime	181.44	300	.0976
M 8	Hydrated lime	244.24	300	.0986
M 9	Precipitated carbonate	323.92	300	.0996
M 10	Ground limestone	354.68	300	.1006
M 11	Ground dolomite	305.62	300	.0981
M 12	None		300	.1048
M 13	Burnt lime	181.44	750	.0983
M 14	Hydrated lime	244.24	750	.0976
M 15	Precipitated carbonate	323.92	750	.0927
M 16	Ground limestone	354.68	750	.1031
M 17	Ground dolomite	305.62	750	.1059
M 18	None		750	.1087
M 19	Burnt lime	725.76	1,200	.0935
M 20	Hydrated lime	976.94	1,200	.0920
M 21	Precipitated carbonate	1,295.68	1,200	.0996
M 22	Ground limestone	1,418.72	1,200	.0986
M 23	Ground dolomite	1,222.48	1,200	.0988
M 24	None		1,200	.1097
M 25	Burnt lime	725.26		.0805
M 26	Hydrated lime	976.94		.0824
M 27	Precipitated carbonate	1,295.68		.0912
M 28	Ground limestone	1,418.72		.0917
M 29	Dolomite	1,222.48		.0917
M 30	None			.1021
M 31	Magnesium carbonate	1,238.07		.0886
M 32	Magnesium carbonate	1,238.07	750	.1023
	SERIES N, TALL OAT GRASS			
N 1	Burnt lime	181.44		.1107
N 2	Hydrated lime	244.24		.1094
N 3	Precipitated carbonate	323.92		.1114
N 4	Ground limestone	354.68		.1102
N 5	Ground dolomite	305.62		.1109
N 6	None			.1051
N 7	Burnt lime	181.44	300	.1153
N 8	Hydrated lime	244.24	300	.1145
N 9	Precipitated carbonate	323.92	300	.1143

TABLE 5 (continued).

Rim No.	Treatment. Liming material.	Quantity per rim.	Manure.	Nitrogen on moisture-free basis.
		Grams.	*Grams.*	*Percent.*
N 10	Ground limestone	354.68	300	.1153
N 11	Ground dolomite	305.62	300	.1163
N 12	None		300	.1198
N 13	Burnt lime	181.44	750	.1209
N 14	Hydrated lime	244.24	750	.1229
N 15	Precipitated carbonate	323.92	750	.1214
N 16	Ground limestone	354.68	750	.1291
N 17	Ground dolomite	305.62	750	.1190
N 18	None		750	.1173
N 19	Burnt lime	725.76	1,200	.1170
N 20	Hydrated lime	976.94	1,200	.1143
N 21	Precipitated carbonate	1,295.68	1,200	.1203
N 22	Ground limestone	1,418.72	1,200	.1211
N 23	Ground dolomite	1,222.48	1,200	.1216
N 24	None		1,200	.1183
N 25	Burnt lime	725.26		.1016
N 26	Hydrated lime	976.94		.1036
N 27	Precipitated carbonate	1,295.68		.1074
N 28	Ground limestone	1,418.72		.1117
N 29	Dolomite	1,222.48		.1082
N 30	None			.1140
N 31	Magnesium carbonate	1,238.07		.1036
N 32	Magnesium carbonate	1,238.07	750	.1170

DISCUSSION OF THE SOIL RESULTS.

In work of this kind too much importance should not be attached to the nitrogen content of a single rim, because of errors in the sampling and in the analytical work, together with possible accidental and unknown happenings which may easily distort a true result. Even the averages from two or three rims, as given in Table 6, may be in error for the same reason, but can be used with at least a larger degree of confidence. So far as these series are concerned, presentation as in Table 6 serves to strengthen materially some of the more important conclusions reached from the results considered as a whole.

To facilitate the comparison of the various averages as given in this table, figures 4 to 8 were prepared. In the charts the height of the black columns indicates the percentage of nitrogen at the end of the 5-year period. The white columns show the percentages of nitrogen at the outset after the various forms of lime and the manurial treatments were made.

If the first four charts, figures 4 to 7, are compared together the strikingly higher percentages of nitrogen in the soil of series N at the end of the 5-year period is evident. The average percentage

TABLE 6.—*Nitrogen content of soil summarized under various experimental conditions at end of 5-year period (Nitrogen percentages calculated to moisture-free basis).*

Series.	Fresh manure per acre.	Lime equivalent per acre.	Nitrogen content of soil to which calcic or other material was applied. None.	Burnt lime.	Hydrated lime.	Precipitated carbonate of lime.	Limestone.	Dolomite.	Magnesium carbonate.
	Tons.	*Tons.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
K	None	2		0.0996	0.1008	0.0967	0.0998	0.1001	
K	12	2		.1016	.1033	.1023	.1051	.1011	
K	30	2		.1043	.1031	.1036	.1057	.1043	
	Average			.1018	.1024	.1009	.1035	.1018	
K	None	8		.0874	.0859	.0930	.0965	.0957	
K	48	8		.1001	.0991	.1031	.1038	.1046	
	Average			.0938	.0925	.0981	.1002	.1002	
K	None	8							0.0993
K	30	8							.1048
	Average								.1021
K	None	None	.1030						
K	12	None	.1028						
K	30	None	.1089						
	Average		.1049						
K	None	None	.1030						
	48	None	.1143						
	Average		.1087						
			NO CROP—SOIL UNDISTURBED.						
L	None	2		.0950	.0957	.0942	.0998	.0942	
L	12	2		.0976	.0950	.0983	.1043	.1008	
L	30	2		.1036	.1016	.1026	.1067	.1087	
	Average			.0987	.0974	.0984	.1036	.1012	
L	None	8		.0889	.0856	.0912	.0950	.0945	
L	48	8		.1013	.1026	.1048	.1041	.1001	
	Average			.0951	.0941	.0980	.0996	.0973	
L	None	8							.0965
L	30	8							.1003
	Average								.0989
L	None	None	.1047						
L	12	None	.1038						
L	30	None	.1059						
	Average		.1048						
L	None	None	.1047						
L	48	None	.1092						
	Average		.1070						

TABLE 6 (continued).

Series	Fresh manure per acre.	Lime equivalent per acre.	Nitrogen content of soil to which calcic or other material was applied. None.	Burnt lime.	Hydrated lime.	Precipitated carbonate of lime.	Limestone.	Dolomite.	Magnesium carbonate.
			NO CROP, SOIL CULTIVATED.						
M	None	2		.0976	.0935	.0978	.0942	.1003	
M	12	2		.0976	.0986	.0996	.1006	.0981	
M	30	2		.0983	.0976	.0927	.1031	.1059	
	Average			.0978	.0966	.0967	.0993	.1014	
M	None	8		.0805	.0824	.0912	.0917	.0917	
M	48	8		.0935	.0920	.0996	.0986	.0988	
	Average			.0870	.0872	.0954	.0952	.0953	
M	None	8							.0886
M	30	8							.1023
	Average								.0955
M	None	None	.1025						
M	12	None	.1048						
M	30	None	.1087						
	Average		.1053						
M	None	None	.1025						
M	48	None	.1097						
	Average		.1061						
			TALL OAT GRASS.						
N	None	2		.1107	.1094	.1114	.1102	.1109	
N	12	2		.1153	.1145	.1143	.1153	.1163	
N	30	2		.1207	.1229	.1214	.1291	.1190	
	Average			.1156	.1156	.1157	.1182	.1154	
N	None	8		.1016	.1036	.1074	.1117	.1082	
N	48	8		.1170	.1143	.1203	.1211	.1216	
	Average			.1093	.1090	.1139	.1164	.1149	
N	None	8							.1036
N	30	8							.1170
	Average								.1103
N	None	None	.1140						
N	12	None	.1198						
N	30	None	.1173						
	Average		.1170						
N	None	None	.1140						
N	48	None	.1183						
	Average		.1162						

of nitrogen for series N is 0.1144, but the average from the other three series is only 0.0993. In explanation of this result, attention is called to the fact that tall oat grass makes a vigorous growth in this climate and remains green almost thruout the year. Ap-

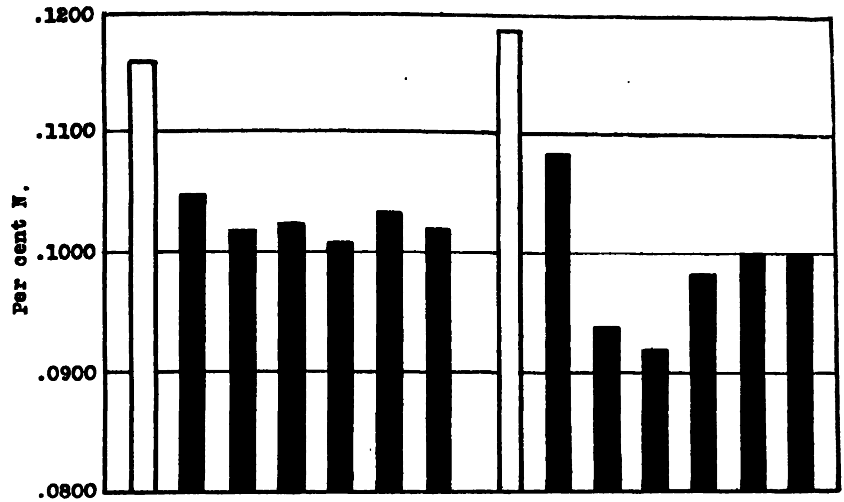


FIG. 4. Effect of various forms of lime on the nitrogen content of the soil: Series K, crops grown, lespedeza and cowpeas. In figures 4 to 7, the left half of the graph shows the results from the application of 2-ton equivalents, and the right half of 8-ton equivalents. In each half, the white column at the left represents the original nitrogen content. The results from the various applications are shown in the following order: No lime; burnt lime; hydrated lime; precipitated carbonate; ground limestone; and dolomite.

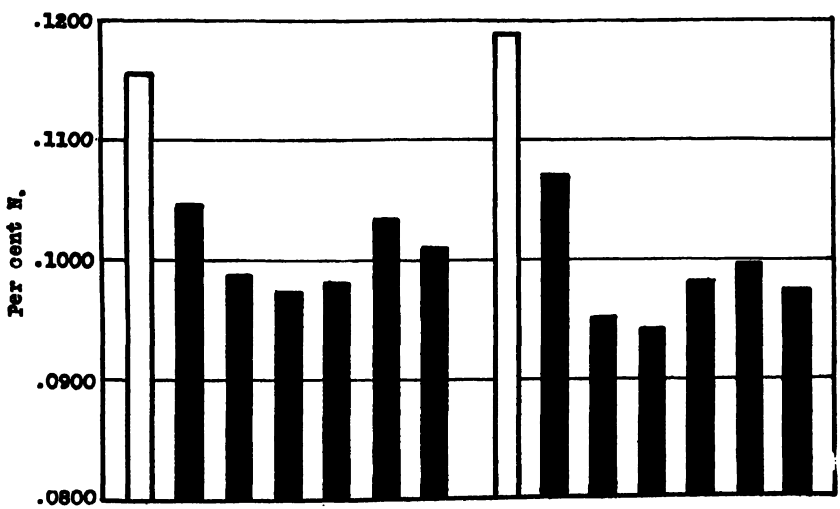


FIG. 5. Percentages of nitrogen in soil in Series L, no crop, soil undisturbed. See legend to figure 4.

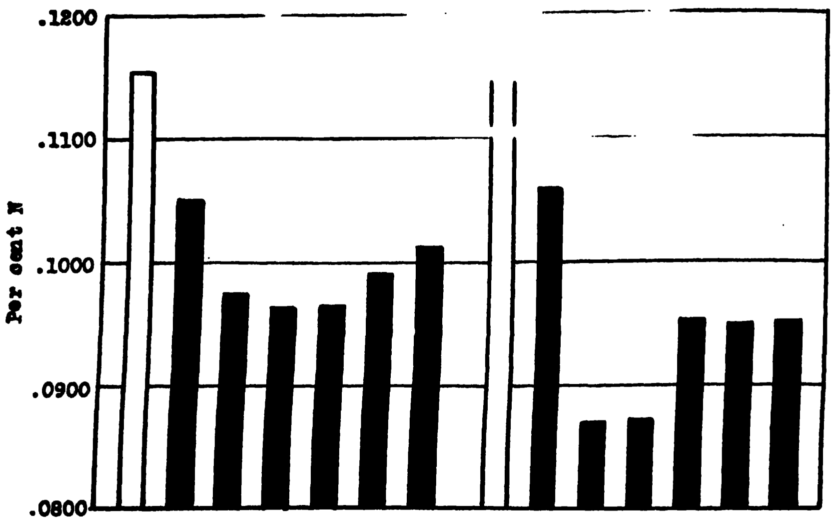


FIG. 6. Percentages of nitrogen in soil in Series M, no crop, soil cultivated. See legend to figure 4.

FIG. 7. Percentages of nitrogen in soil in Series N, tall oat grass. See legend to figure 4.

parently, therefore, it conserves the soil supply of nitrogen to much greater [illegible] than the cowpea [illegible] annual growing only thru the summer [illegible] thruout the rest of the year, so that a large loss of nitrogen by leaching would be expected. A slightly larger amount of soil nitrogen was found in series K, where the cowpeas were grown, than in either series L or M, which were uncropped. Series L, which was undisturbed, except to scrape off or pull up any weed growth that started, showed a somewhat higher content of nitrogen than series M, which was cultivated each year. The average percentage of nitrogen for each series is 0.1008 for K, 0.0995 for L, and 0.0969 for M. In the consideration of the outcome from series L and M, attention is called to the fact that moss more readily covered the soil of series M than of any other and it is possible that this growth, tho at no time heavy, had a conserving effect on the nitrogen content of the soil. At any rate, the greater moss growth on series L, as well as the frequent stirring of the soil in series M, should be taken into consideration in the interpretation of the slight difference in the outcome of these two series.

In all four series an appreciably greater loss of soil nitrogen is evident under the 8-ton equivalents than under the 2-ton. This is true either with or without the addition of manure. Also it is true of each kind of liming material but is especially noticeable where either the oxid or the hydrated forms were applied.

In series K, L, and M, the 2-ton equivalents accelerated the loss of nitrogen, but in series N, where the tall oat grass grew, practically the same amount of nitrogen was found at the end of the five years as at the outset. It may even be said that, within the limits of error, there was no decrease in the percentage of total soil nitrogen in spite of the known quantity removed by the crops and the loss by leaching, which must have been considerable. As no legumes were allowed to grow in this series, nitrogen fixation, by azotabacter or the like, is strongly suggested.

Figures 4 to 7 and Table 7 show that there is no significant difference between the effects of burnt lime, hydrated lime, and precipitated carbonate when applied on the 2-ton basis, the average percentage of nitrogen for all four series being 0.1035 for the burnt lime, 0.1030 for the hydrated lime, and 0.1029 for the precipitated carbonate, as compared with 0.1080 where no lime was applied. All three forms, therefore, occasioned a material reduction in the nitrogen content of the soil. Where the relatively coarse limestone and

dolomite were applied a[illegible] resulted, but less than for the other forms, the percentages being 0.1062 for the limestone and 0.1050 for the dolomite. Under the 8-ton treatments greater losses of soil nitrogen took place in all cases. Burnt lime and hydrated lime gave almost duplicate outcomes, the percentage of nitrogen being 0.0963 for the former and 0.0957 for the latter, but the effects of the precipitated carbonate, instead of being in harmony with the oxid and hydrate, were in close accord with the results from the limestone and dolomite, the percentages of nitrogen being 0.1014 for the precipitated carbonate, 0.1029 for the limestone, and 0.1019 for the dolomite.

TABLE 7.—*Nitrogen content of soil following various lime treatments, as shown by soil samples at close of 5-year period (All series averaged, 12 rims for each 2-ton rate and 8 rims for each 8-ton rate).*[a]

Rate of liming.	Lime treatments.					
	None.	Burnt lime.	Hydrated lime.	Precipitated carbonate.	Ground limestone.	Ground dolomite.
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*	*Percent.*
2-ton......	0.1080	0.1035	0.1030	0.1029	0.1062	0.1050
8-ton......	.1095	.0963	.0957	.1014	.1029	.1019

[a] Nitrogen content at outset: 2-ton basis, 0.1161 percent; 8-ton basis, 0.1187 percent; but without lime, 0.1165 percent and 0.1195 percent, respectively.

That the oxid and hydrate should show closely agreeing effects thruout the series is not surprising, for the oxid would be almost immediately hydrated in the soil. Their action appears to be identical. MacIntire (4)[3] found that both oxid and hydrated lime applied at the 2-ton rate attained maximum carbonation in the course of 5 days. It is not strange, therefore, that these three forms should give similar results when applied at the low rate. Just why the precipitated carbonate, when applied at the 8-ton rate, should produce results different from those obtained from the same equivalents of oxid and hydrate, but similar to those from the ground limestone and ground dolomite, is not altogether clear. More time was required for the oxid and hydrate to carbonate. The carbonate form also was found to persist in the soil under the 8-ton but not under the 2-ton application, that is, the latter silicated long before the former, the quantity being too great to be quickly changed over. The

[3] Reference is to "Literature cited," p. 205.

results from the heavy ap[illegible] both the oxid and the [illegible] nitrogen as compared with the other forms used.

Precipitated mag[illegible] applied [illegible] rate both with and without manure, induced losses of soil nitrogen comparable to those which followed liming with precipitated calcium carbonate. This result can well be seen from figure 8, in comparison with figures 4 to 7.

RESULTS OBTAINED ELSEWHERE.

Numerous results obtained at the New Jersey station have shown that liming with ground oyster shells may produce decided losses of soil nitrogen. In a rotation of corn, oats, wheat, and timothy, the limed plats were found to have lost, in 10 years, 240 pounds more nitrogen per acre than the unlimed plats (3). In another experimental series (2), with timothy and clover, the content of soil nitrogen appeared to be increased on range 1, but to have remained constant on range 2. On range 3, with rye, vetch, and crimson clover, the effect of liming on the nitrogen content of the soil was not appreciable. On the other hand, on range 4, where rye, cowpeas, oats, and peas took the place of timothy and clover, the limed soil lost nitrogen as compared with the unlimed. In these experiments the authors state, "The limed plots, with only slight exception, have yielded distinctly larger crops and more total nitrogen than the unlimed plots."

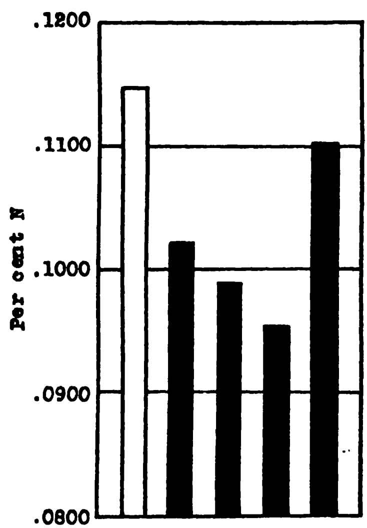


FIG. 8. Results with magnesium carbonate, 8-ton equivalents. Columns from left to right represent original and Series K, L, M, and N.

In these New Jersey experiments it seems evident that liming produced loss of soil nitrogen where no legume was grown or even where certain legumes were grown, but that with such legumes as red clover and crimson clover the gains in nitrogen might offset or even more than offset the losses produced by liming.

At the Pennsylvania station, as a part of their general fertilizer series of experiments, begun in 1881, studies were made of the effects of applications both of burnt lime and of ground limestone. The burnt or caustic lime was applied at the rate of 2 tons per acre once every four years and the ground limestone at the same rate every two years, so that the chemical equivalents were practically the same. In 1899, or eighteen years after the experiments were begun, the soil from the variously treated plats was analyzed by Hess and again in 1911 by MacIntire, particular attention being given in each instance to the determination both of nitrogen and of organic matter.

The conclusions reached by Hess are stated by Frear (1) as follows:

1. That lime alone has a markedly destructive effect, direct or indirect, upon the soil humus.

2. That a like destructive action occurs, as would be anticipated when lime is used with manure, as shown by comparison with the soil that received a like manure dressing without lime.

3. That carbonate of calcium is less destructive, since the soil of plat No. 34 shows considerably more humus than the untreated soil.

Unfortunately no soil samples were taken at the outset of these experiments so that the original humus content is not known, hence the results gotten by Hess do not furnish the conclusive evidence desired.

The two sets of nitrogen determinations, as given in Table 8, are taken from Bulletin 261 of the Pennsylvania State Department of Agriculture (p. 149). The analyses made by MacIntire of the 1911 samples, while confirmatory of the figures obtained so far as nitrogen and humus contents of the soils under the various treatments were concerned, showed that in the 12 years which had intervened probably no material changes had taken place in the relative nitrogen content of these plats. Three of them indicated a gain and the other two a loss, but there was no indication that the burnt lime had produced, in the 12-year period, a greater loss of nitrogen than the ground limestone. In connection with these experiments it should be mentioned that the plats were large and somewhat lacking in uniformity, making sampling difficult, so that entirely concordant results from sampling conducted by different men would not be expected.

Perhaps both sets of conclusions were right, that is, there may have been a greater loss of nitrogen for the first term of years from

the caustic lime than from the ground limestone, but in the last term of years the ground limestone caused as much or more loss than the burnt lime. Results suggesting such a possiblity have been obtained in the cowpea-wheat rotation experiments at the Tennessee station and will be referred to later.

TABLE 8.—*Nitrogen content of soil from certain plats of the general fertilizer experiments at the Pennsylvania station (Pa. Dept. Agr., Bul. 261, p. 156).*

Plat treatment.	Hess, 1899–1900.	MacIntire, 1911.	Change in 12 years.
	Percent.	*Percent.*	*Percent.*
Untreated soil	0.1244	[a]0.1122	−0.0122
Manure (6 T.)	.1508	.1523	.0015
Manure (6 T.) and lime	.1468	.1589	.1021
Lime	.1172	.1199	.0027
Ground limestone	.1341	.1222	−.0119

[a] Representing Plats 24 only, the four untreated plats adjacent to the four limed plats, whereas the 1899–1900 samples represented Plats 1, 14, 24, and 36 collectively.

Attention will now be called to the results obtained from field experiments at the Tennessee station (5) on a soil similar to that used in the rims. Liming with burnt lime at the rate of 1,800 pounds per acre very materially increased the losses of soil nitrogen under each of a number of experimental conditions, such as the continued removal of all crops, the turning under of the cowpea crop, and the removal of only the wheat crop. The limed plats lost nearly 20 pounds more of nitrogen per annum than the unlimed for the first 5 years. Since that time unpublished data show that the differences between the percentages of nitrogen in the limed and unlimed plats gradually became less and less until in the course of 10 years from the beginning of the experiment there was no appreciable difference between them. A second application of burnt lime at the end of 12 years failed to change the situation in the following two years. Therefore, in conclusion, the writers wish to emphasize the point that while liming may produce marked changes in the content of soil nitrogen for a few years, after the initial liming there is at least the possibility that these differences may disappear later.

THE CROP YIELDS.

One crop of lespedeza and three crops of cowpeas, all harvested at the hay stage, were grown on series K. On series N tall oat grass was grown continuously. All the crops were removed. The yields of

lespedeza on series K were very irregular, due in large part to the very uneven stands obtained. There was also some trouble with the cowpeas in this respect. The stands of tall oat grass were excellent almost thruout the series. The yields are summarized in Table 9, which gives the average total hay production per rim, and also the nitrogen removed by the hay under each lime treatment specified.

TABLE 9.—*Summary of yields per rim of lespedeza and cowpea hay and of tall oat grass hay, with the nitrogen removed by the hays during the 5-year period.*

Form of lime.	Series K, Lespedeza and cowpea hay.		Series N, Tall oat grass hay.	
	Hay.	Nitrogen.	Hay.	Nitrogen.
	Grams.	*Grams.*	*Grams.*	*Grams.*
2-ton basis:				
Burnt	934.7	23.04	690.4	8.23
Hydrated	933.0	23.16	718.6	8.58
Precipitated	818.8	20.60	626.5	7.56
Limestone	775.7	19.62	659.0	7.77
Dolomite	969.8	24.18	571.3	6.85
None	461.4	11.06	436.0	5.35
8-ton basis:				
Burnt	796.9	21.02	841.1	9.83
Hydrated	728.9	19.26	937.5	10.96
Precipitated	732.0	18.40	847.4	9.90
Limestone	1,093.3	26.50	849.3	9.93
Dolomite	1,100.0	26.78	814.4	9.54
None	733.4	18.46	574.1	6.89
Averages	839.8	21.01	713.8	8.45

DISCUSSION OF THE CROP RESULTS.

Because of the uneven stands obtained in series K, special stress can not be laid on the legume yields. It is evident, however, that liming with any material appreciably increased the yields, tho at the 8-ton rate the burnt lime, hydrated lime, and precipitated carbonate gave low yields as compared either with those obtained at the 2-ton rates of the same materials or at the 8-ton rates of limestone and dolomite. This result is attributed in large part to the highly flocculating effect of the heavy applications of these three materials and a consequent rapid drying out of the soil after a rain resulting in low germination of the seed. Similar results have been noticed in field experiments at the station farm, where a single ton of burnt lime has been found to produce an unfavorable effect on the structure of this particular type of soil so that poor stands of cow-

peas were obtained, whereas on adjoining unlimed plats the stands were normal.

Perhaps the most important conclusion to be reached from the crop results is that the 8-ton applications of both the oxid and hydrate forms of lime resulted in appreciable waste of soil nitrogen from the cropped series K and N, that is, the losses from the soil are not counterbalanced by a corresponding increase of nitrogen in the crops.

In series N liming at either rate materially increased the yields but no lowering of the yields resulted from the 8-ton treatments of either the oxid or hydrate, as was the case with series K. In fact, the increases from the 8-ton treatments surpassed those from the 2-ton in all cases.

As may be calculated from Table 9, the nitrogen contained by the leguminous crops is nearly two and one-half times that found in the nonleguminous crops of tall oat grass. In either series if the nitrogen found in the crop be added to that found in the soil at the end of the 5-year period, more nitrogen is obtained than was present at the outset in the surface soil. The subsoil was rather heavy and tenacious and showed on the average a content of 0.0824 percent nitrogen in the upper 6 inches. The subsoil would be expected, however, to yield nitrogen to the crops grown but, since there are no data to show the quantity derived from this source, the matter will not be discussed further.

EFFECT OF MAGNESIUM CARBONATE ON CROP YIELDS.

As previously mentioned, the effect of magnesium carbonate on the loss of soil nitrogen was similar to that of the precipitated calcium carbonate. The effect on the crop yields was, however, quite different, for the magnesia treated rims produced only scanty crops the first year (1914). Afterwards the normal crops were produced by them.

SUMMARY.

1. Five forms of lime, viz, oxid, hydrate, precipitated carbonate, ground limestone, and ground dolomite, and precipitated magnesium carbonate were used in four series of experiments with the object of determining their comparative effects on the soil content of total nitrogen. The lime materials were applied at each of two rates on the basis of 2 and 8 tons per acre of CaO. These applications were made both with and without the addition of stable manure. Results are reported for the period of the first five years.

2. The experiments were made in 128 rims exposed to open air

conditions. Each rim was 1 foot deep and 2.225 feet in diameter, the surface area of exposed soil being one ten-thousandth of an acre.

3. Thirty-two rims were used in each of four similarly treated series designated as K, L, M and N.

In series K one crop of lespedeza and three crops of cowpeas were grown and removed as hay. In series L no crop was grown and the soil was disturbed as little as possible thruout the period. In series M no crop was grown but the soil was cultivated from time to time thruout the growing season as for corn. In series N tall oat grass was grown continuously.

4. Series K, L, and M all showed marked and very similar losses of soil nitrogen. Series N showed the least loss of soil nitrogen. At the end of the 5-year period the average percentage of soil nitrogen in the rims of series N was 0.1144, but the average from the three other series was only 0.0993. The average percentage of nitrogen in a series at the outset was 0.1174.

5. All forms of lime gave rise to a loss of soil nitrogen, the 8-ton rates noticeably surpassing the 2-ton in this respect.

6. At the 2-ton rate the oxid, hydrate, and precipitated carbonate induced losses similar in extent. These losses were especially apparent in series K, L, and M. The 2-ton application of limestone and dolomite induced appreciable losses in series K, L, and M, but not in series N.

7. At the 8-ton rate the oxid and hydrate gave rise to large losses of soil nitrogen in all series, especially in K, L, and M. The precipitated carbonate, ground limestone, and dolomite produced losses which were similar one to the other, but much less than was produced by either the oxid or hydrate.

8. Thruout the series there was no significant difference between the effect of the oxid and hydrate, these forms inducing the greatest losses, but especially at the higher or 8-ton rate of application.

9. As might be expected from the relative coarseness of their particles, ground limestone and dolomite induced the least loss of soil nitrogen. On the other hand, the very fine, precipitated carbonate, while inducing losses almost identical with the oxid and hydrate when applied at the 2-ton rate, ranked with the ground limestone and dolomite in producing the smallest losses when applied at the 8-ton rate.

10. The precipitated magnesium carbonate induced losses comparable with the precipitated calcium carbonate.

11. The lespedeza and cowpea crops of series K produced slightly more dry matter than the tall oat crops of series L. The nitrogen removed by the cowpeas, however, was nearly two and a half times that removed by the tall oat grass.

12. All forms of lime produced greatly increased yields of both crops, but distinctions between the effect of the different forms can hardly be made. At the 8-ton rate, however, the ground limestone and dolomite produced much larger yields of cowpeas than did any other form, perhaps due to the highly flocculating action of the other forms, thus changing, apparently adversely, the soil structure. Corresponding influences on yields did not, however, appear in the case of the tall oat grass.

13. The evidence is conclusive that both the oxid and hydrate when applied at the 8-ton rate resulted in a waste of nitrogen, the losses being greater from the soil but with no more nitrogen in the crops than either precipitated carbonate, ground limestone, or dolomite were applied.

14. Under cropping and with liming at the 2-ton rate no one form plainly produced a greater loss of soil nitrogen than the others.

15. Experimental results from the New Jersey station show that with certain crops, nonlegumes in particular, marked losses of soil nitrogen followed liming with ground oyster shells, but that the nitrogen loss was entirely overcome where either red or crimson clover entered into the rotation.

16. The results obtained in field experiments at both the Pennsylvania and Tennessee stations indicate the possibility of material losses of soil nitrogen following the initial use of burnt lime, but with greatly reduced or even no effect of this kind from later liming.

LITERATURE CITED.

1. FREAR, WM. Sour soils and liming. Pa. Dept. Agr. Bul. 261, p. 149. 1915.
2. LIPMAN, J. G., and BLAIR, A. W. The lime factor in permanent soil improvement. *In* Soil Sci., v. 9, no. 5, pp. 91–114. 1920.
3. ——. Field experiments on the availability of nitrogenous fertilizers, 1908–1917. *In* Soil Sci., v. 9, no. 5, p. 391. 1920.
4. MACINTIRE, W. H. The carbonation of burnt lime in soils. *In* Soil Sci. v. 7, no. 5, pp. 351 and 354. 1919.
5. MOOERS, C. A. The effect of liming and of green manuring on the soil content of nitrogen and humus. Tenn. Agr. Exp. Sta. Bull. 96, pt. 3, pp. 37 and 43. 1912.

THE VALUE OF LIMING IN A CROP ROTATION WITH AND WITHOUT LEGUMES.[1]

JACOB G. LIPMAN.[2]

This is a brief record of certain experiments conducted by the New Jersey Agricultural Experiment Station. These experiments have been in progress for thirteen years and deal in part with the lime factor in the transformation and accumulation of nitrogen in soils. The land used for these experiments had been neglected for many years prior to 1908. The information at hand seems to indicate that lime had not been used on this land for 25 or 30 years prior to the beginning of the experiments. In fact, there is no evidence that this land had ever received an application of lime. At the time of the beginning of the experiments lime requirement determinations were made by the Veitch method. This showed a lime requirement of about 1,600 to 2,000 pounds of lime (CaO) per 2,000,000 pounds of soil.

In the spring of 1908 the field was laid out in twentieth-acre plats. These have been used since for nitrogen availability studies as well as for nitrogen accumulation studies. Hence, different rotations have been employed. Some of them include legumes; others do not. The rotation used in connection with Plats 1-*A* to 20-*B* consists of corn, oats, wheat, and timothy for two years. The rotation used in connection with Plats 21 to 27 consists of corn followed by rye, vetch, and crimson clover as a cover crop; oats followed by soybeans and cowpeas as a cover crop; wheat; and timothy and clover for two years. The rotation used in connection with Plats 28 to 34 consists of corn followed by rye, vetch, and crimson clover as a cover crop; potatoes; rye; and timothy and clover for two years. The rotation on Plats 35 to 41 consists of corn with rye, vetch, and crimson clover as a cover crop; potatoes with rye as a cover crop; tomatoes with rye, vetch, and crimson clover as a cover crop; lima beans with rye, vetch, and crimson clover as a cover crop; and cucumbers with rye and vetch as a

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920.

[2] Director of the New Jersey Agricultural Experiment Station and dean of the New Jersey College of Agriculture and Mechanic Arts, New Brunswick, N. J.

cover crop. The rotation used for Plats 42 to 48 consists of corn with rye, vetch, and crimson clover as a cover crop; oats and peas followed by millet; rye and vetch followed by rape; rye followed by cowpeas and the latter by rye as a cover crop; and oats and peas followed by cowpeas. It will be noted then that Plats 21 to 48 were employed for the study of four distinct rotations in which legumes have been included and in which the lime factor has been studied.

Plats 21, 28, 35, and 42 have received no applications of lime. Plats 25, 32, 39, and 46 have received applications of magnesian limestone at the rate of a half ton per acre once in each 5-year rotation. Plats 26, 33, 40, and 47 have received corresponding applications of 2,000 pounds per acre; and Plats 27, 34, 41, and 48 have received corresponding applications of 4,000 pounds per acre.

A comparison thus becomes possible between Plats 1-*A* to 20-*A*, unlimed, and the corresponding Plats 1-*B* to 20-*B*, limed, used in connection with a rotation of nonlegumes. A comparison becomes possible, also, between plats receiving no lime, a half ton, 1 ton, and 2 tons per acre in connection with four different rotations including leguminous crops. No attempt will be made to review in this paper the data secured for the period 1908–1912 inclusive. The data discussed here represent the returns for the years 1913 to 1918, inclusive. It should be added here, for the sake of completing the record, that Plats 1-*A* to 20-*B* annually received, with few exceptions, acid phosphate at the rate of 640 pounds per acre and muriate of potash at the rate of 320 pounds per acre, in addition to the special nitrogen treatment. On the other hand, Plats 21 to 48, used for the legume rotations, received annually 300 to 400 pounds of acid phosphate, 100 pounds of muriate of potash, and nitrogen in the form of nitrate of soda, ground fish, or tankage equivalent to about 15 to 30 pounds per acre.

Table 1 shows the yields obtained from Plats 1 and 7, which have received no fertilizer at all since 1908; from Plats 4 and 19, which have received acid phosphate and muriate of potash only; from Plat 6, which has received annual applications of 16 tons of horse manure per acre aside from the acid phosphate and muriate of potash; from Plat 9, which has received annually nitrate of soda at the rate of 320 pounds per acre aside from the acid phosphate and muriate; and from Plat 18, which has received annual applications of horse manure, nitrate of soda, acid phosphate, and muriate. A comparison is given in each case of the corresponding limed and unlimed plats.

TABLE 1.—*Yields of nitrogen in pounds per acre for the years from 1913 to 1918 in rotations without legumes.*

Plat No.	Corn, 1913.		Oats, 1914.		Wheat, 1915.		Timothy, 1916.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
1......	24.65	30.84	17.32	16.58	16.68	23.45	14.56	17.51
7......	45.39	13.69	8.70	11.88	18.70	7.34	20.24	6.53
4......	39.81	23.03	11.44	20.54	16.36	23.57	15.41	14.84
19......	32.13	20.73	14.54	17.06	20.94	18.71	19.52	12.30
6......	44.84	60.13	24.14	35.94	54.25	56.82	34.41	37.93
9......	53.59	38.72	18.60	28.64	34.06	45.38	28.57	26.19
18......	74.10	72.90	35.90	29.88	69.10	72.14	37.94	38.39
Total....	314.51	260.04	130.64	160.52	230.09	247.41	170.65	153.69

Plat No.	Timothy, 1917.		Corn, 1918.		Total.		Annual average.	
	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.	Limed.	Unlimed.
1......	6.62	13.32	47.53	40.57	127.36	142.27	21.23	23.71
7......	7.28	3.74	43.85	24.20	144.16	67.38	24.03	11.23
4......	9.54	8.51	49.33	39.84	141.89	130.33	23.65	21.72
19......	19.99	7.41	59.61	38.28	166.73	114.49	27.79	19.08
6......	31.36	36.36	70.91	71.23	259.91	298.41	43.32	49.73
9......	23.81	28.29	60.71	54.46	219.34	221.68	36.56	36.95
18......	46.24	41.99	95.23	91.51	358.51	346.81	59.75	57.80
Total....	144.84	139.62	427.17	360.09	1,417.90	1,321.37	236.33	220.22

It will be noted that the soil of Plat 7-*A* is not as productive as that of Plat 7-*B*. The average yield of nitrogen for Plat 7-*B* has been 24.03 pounds per acre, while the average yield of nitrogen from the unlimed plat 7-*A* has been 11.23 pounds per acre. Aside from that the differences are slight. Even with the returns from Plats 7-*A* and 7-*B* included, the annual yield of nitrogen from the seven limed plats has been 33.76 per acre, while the corresponding yield from the unlimed plats has been 31.46 pounds per acre, or a difference of 2.30 pounds per acre only. The yield of nitrogen from Plat 6-*B*, receiving annually 16 tons of horse manure per acre, has been 43.32 pounds, whereas the corresponding yield from the unlimed plat 6-*A* has been 49.73 pounds of nitrogen per acre. Plat 18-*B* has yielded 59.75 pounds of nitrogen per acre, and Plat 18-*A* 57.80 pounds of nitrogen per acre. It will be noted, therefore, that with the rotation of non-legumes as employed, the use of 1 ton of ground limestone in 1908 and the corresponding use of 2 tons of ground limestone per acre in 1913 and 1918 have shown no marked advantage from the lime.

An entirely different picture is shown by the rotations in which legumes have been included, as shown in Table 2.

TABLE 2.—*Yields of nitrogen in pounds per acre in rotations with legumes.*

Plat No.	1913.	1914.	1915.	1916.	1917.	1918.	Total.	Annual average.	Increase.
21.......	25.61	19.65	24.13	35.50	19.91	48.25	173.05	28.84	—
25.......	41.16	21.48	30.47	74.68	27.81	60.28	255.85	42.64	13.80
26.......	52.28	23.38	29.59	106.09	32.26	62.56	306.16	51.03	22.19
27.......	54.18	24.02	29.74	99.77	34.56	64.83	307.10	49.51	20.67
28.......	33.29	22.47	28.19	53.89	27.30	55.01	220.15	36.69	—
32.......	56.52	21.72	29.38	79.16	34.41	57.05	278.24	48.04	11.35
33.......	62.12	21.14	30.58	90.80	37.52	60.00	302.16	50.36	13.67
34.......	60.85	19.26	28.47	96.63	34.65	69.24	309.11	51.52	14.83
35.......	42.98	15.42	40.55	16.69	9.50	58.50	183.64	30.61	—
39.......	46.52	16.41	42.86	19.30	16.94	69.90	211.93	38.65	8.06
40.......	56.28	19.25	46.68	23.16	16.94	70.05	232.36	38.73	8.12
41.......	62.05	16.34	48.71	14.31	15.86	72.92	230.19	38.36	7.75
42.......	36.95	29.94	23.74	52.02	59.72	59.40	261.79	43.63	—
46.......	39.75	40.13	79.32	85.68	104.83	62.79	412.50	68.75	25.12
47.......	43.02	39.44	109.78	95.93	104.92	58.29	451.38	75.23	31.60
48.......	44.78	42.85	116.71	78.00	119.38	56.52	458.24	76.37	32.74

Here marked increases have been obtained from the use of a half ton of ground limestone per acre once in five years. Still more marked increases were secured from 1 ton of ground limestone used once in five years. On the other hand, the employment of 2 tons of magnesian ground limestone per acre instead of 1 ton has not shown any further marked increases in the yield of nitrogen. In Rotation 1, an application of 2,000 pounds of ground limestone produced an average increase in the yield of nitrogen amounting to 22.19 pounds per acre. The corresponding increase in Rotation 2 was 13.67 pounds per acre; in Rotation 3, 8.12 pounds per acre; and in Rotation 4, 31.60 pounds per acre. In some instances, the yields of nitrogen per acre have been very high, as, for example, the yield of 116.71 pounds on Plat 48 in 1915 and 119.38 pounds in 1917. Evidently, Rotation 4 was more effective for the accumulation of atmospheric nitrogen than were any of the other rotations, particularly Rotation 3. In round figures, the average yield of nitrogen with 1 ton of ground limestone per acre once in five years was 51 pounds for Rotation 1; 50 pounds for Rotation 2; 38 pounds for Rotation 3; and 75 pounds for Rotation 4. Evidently, the returns in these rotations were due in large measure to the fixation of atmospheric nitrogen, for the average annual application in nitrate of soda, tankage, or ground fish was only 20 pounds. On the other hand, in the nonlegume rotations Plat 9-*B*, which has been receiving annually about 50 pounds of nitrogen in the form of nitrate of soda, has yielded only an average of 36.56 pounds of nitrogen.

TABLE 3.—*The influence of lime on the yield of nitrogen in rotations with legumes, as shown by increases over unlimed plats.*

	No lime.	1,000 lbs. lime.	2,000 lbs. lime.	4,000 lbs. lime.
Annual yield of nitrogen per acre, lbs......	34.94	49.52	53.84	53.94
Increase due to lime, lbs.................	—	14.58	18.90	19.00

Table 3 shows that for the period from 1913 to 1918 inclusive the increase due to the use of 1 ton of ground limestone per acre in each 5-year period has been, approximately, 19 pounds per acre. The corresponding increase from applications of 4,000 pounds of ground limestone per acre have not been larger.

It will be evident, therefore, that:

1. In rotations of nonlegumes lime is not a vital factor in increasing nitrogen yields except in the case of soils well supplied with organic matter or so deficient in lime and other basic materials as to lead to textural deterioration or the formation of toxic compounds of aluminum and iron.

2. With rotations of nonlegumes it is difficult and uneconomical to maintain an adequate supply of nitrogen in the soil.

3. Crop rotations which include legumes show the importance of lime for the proper accumulation of nitrogen from the atmosphere. Different soils may react differently as to amounts and kinds of lime employed. Where the lime requirements of the land are more or less pronounced, the use of lime becomes an efficient factor in maintaining an adequate supply of nitrogen in the land.

LIMING AS RELATED TO FARM PRACTICE.[1]

FRANK D. GARDNER.[2]

The art and practice of liming soils is much older than the science relating to the subject. The practice dates back to the time of Hesiod, 1,100 years before the beginning of the Christian era. The knowledge gained during this long period relative to the practice of liming soils has, in the absence of records, been handed down from generation to generation by word of mouth and has never found its

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920. Contribution from the Pennsylvania Agricultural Experiment Station, State College, Pa.

[2] Professor of agronomy, Pennsylvania State College.

way into print. Available information of a practical nature is, therefore, meager. In any event, it will be more profitable for us to discuss the practice of today with a view to applying our present facts and findings as accumulated by research to the problem at hand. This should be the acid test and may throw some light on the status of our investigations as applied to the big problem of liming soils.

As one dealing with the practice of liming, I may ask, "Do the experimental tests to date cover the field of inquiry? Are the results thus far secured conclusive? Are there other points yet to be cleared up?" As a business proposition, the use of lime on land is not for one year only or for even a few years, but should be considered from the standpoint of a series of years. Whether for a longer or shorter period, does it pay to apply lime to the soil and what evidence have we that it does pay? As a matter of common observation, many practical farmers over a wide range of territory have long been in the habit of applying lime to their fields at intervals. It is interesting to note that the more successful farmers are numbered among the regular users of lime relatively more frequently than the less successful ones. To be more specific, I will cite a few references from experiment station literature relative to the need for lime and the profits from lime. In Bulletin 164 of the Pennsylvania Agricultural Experiment Station, entitled "Lime Requirement of Pennsylvania Soils," the author, Prof. J. W. White, says: "There is no one soil condition more prevalent in the humid region and possibly none that has a greater controlling influence on the growth of crops than soil acidity."

In Circular 36 of the Illinois Agricultural Experiment Station, Prof. J. E. Readhimer says: "To the lack of limestone in the soil is probably attributed more failures with clover than to any other soil condition." In the southern part of Illinois, clover is generally a failure until the soil has received a rather liberal application of lime, after which good stands of clover may be expected nine times out of ten.

In Circular 54 from New Jersey is reported the value of the increase in crop yields for four crop rotations as influenced by magnesian limestone and nonmagnesian limestone. The rotations each extended over five years and received an initial application of 2 tons per acre of ground limestone of the kinds above mentioned. At that time, the cost of such ground limestone was $2.50 per ton. The value of increase for each rotation and for each kind of limestone is as follows:

Rotation.	Magnesian limestone.	Non-magnesian limestone.
No. 1, General farm crops	$34.75	$23.93
No. 2, General farm crops and potatoes	21.22	16.50
No. 3, Market garden crops	35.48[a]	60.86
No. 4, Forage crops	23.25	31.13

[a] Diseased.

WHEN IS LIME NEEDED?

Lime serves several purposes in the soil, but we will here consider only those relating to soil acidity. The symptoms of soil acidity are manifest to those having studied the subject, first by the character and condition of vegetation. These symptoms are afterwards verified by different tests. The vegetative indications vary with different sections of the country, depending upon the natural flora of the locality. In all cases, however, the partial or complete failure of those crops common to the locality most sensitive to soil acidity and the encroachment on the land of acid-tolerant species of weeds and grasses are the first symptoms of soil acidity. The most common test to verify the suspicion is that made with neutral blue litmus paper. There are a number of quantitative tests familiar to all of you. Several are in use at different experiment stations and yet no two will give comparable results.

In Pennsylvania, especially on the limestone soils, the first symptoms of soil acidity are the failure of common red clover and the occurrence of sorrel (*Rumex acetosella*). In the DeKalb region of the State the wild daisy, yellow trefoil, poverty grass, and dewberries are also indicators of soil acidity, while in the glaciated regions, paintbrush is the most common weed on acid soils.

In New York, Barker reports that indications of the need of lime are the prevalence of sorrel and paintbrush, the failure of red clover, and the turning of blue litmus paper red when brought in contact with the moist soil.

In Iowa, Stevenson reports horsetail rush, sheep sorrel, corn spurry, and wood horsetail as weeds indicating soil acidity. Acidity may also be suspected wherever red clover, sweet clover, and alfalfa will not make satisfactory growth.

Fortunately, our common farm and garden crops manifest a wide range in their tolerance for soil acidity. This makes possible crop rotations with acid-resistant crops on extremely acid soils far removed from sources of lime supplies. It is interesting to note that in general those crops most sensitive to acidity are the ones that usually remove from the soil the largest amount of lime and magnesia. The crops most sensitive to acidity and at the same time most

responsive to applications of lime are alfalfa, red clover, Canada pea, garden pea, soybean, cowpea, lettuce, beet, cabbage, cauliflower, celery, spinach, onion, pepper, cantaloup, and barley Those less dependent on lime and more tolerant of acidity are the Irish potato, sweet potato, carrot, watermelon, blackberry, strawberry, buckwheat, rye, corn, redtop, cotton, tobacco, peanuts, Japan clover, and garden beans.[3]

EXTENT TO WHICH LIME IS NEEDED.

I believe that all of the experiment stations in the States north of those bordering on the Gulf and east of the Mississippi River have issued circulars or bulletins relating to the use of lime on land. A number of these experiment stations have made estimates or actual surveys to determine the percentage of agricultural lands actually in need of lime. Bulletin 164 from the Pennsylvania station reports results of 1,474 lime requirement determinations on as many samples collected from 50 counties in the State. It found 72 percent of the soils tested in need of lime. These samples were taken from soils that had, in many cases, recently been limed, as well as from fields that never had been limed or that had received lime at some rather remote period. In New York State Station Bulletin 430, Barker reports that three-fourths or more of the soils of New York would be benefited by liming. These soils call for lime at the rate of from 1 ton to 10 tons of limestone per acre as determined by actual tests. Just what are the corresponding amounts of limestone most profitable to use is another question. In New Jersey Extension Circular No. 7, Dickey says 80 to 90 percent of the soils of New Jersey need lime. In Iowa Circular No. 58, Stevenson reports that 60 percent of the soils of that State are acid and need lime. Miller, in Missouri Station Bulletin 146, says two-thirds of the soils in that State need lime from insignificant amounts to as much as 5 or 6 tons of limestone per acre. One-fourth of them need 2 tons of limestone or more per acre. From Florida, we have the report that two-thirds of the soils in that State are acid. This estimate is from an examination of 189 samples collected from 17 counties. From these statements, it is evident that the need of lime on land is very general thruout the humid region of the United States.

[3] See Tenn. Agr. Expt. Bul. 96, p. 20.

CAUSES OF SOIL ACIDITY.

There are many factors that contribute to soil acidity and it is quite certain that our knowledge on this point is as yet incomplete. I will, therefore, mention only a few of the principal causes such as:

1. The loss of lime from the soil by leaching.
2. The removal of lime in farm crops.
3. The addition of acid to the soil in certain fertilizers.
4. The formation of acids thru the decomposition of crop residues and organic manures.
5. The contamination of soils by gases and fumes from coke ovens, smelters, factories, etc.

OTHER IMPORTANT REASONS FOR LIMING.

In addition to correcting possible soil acidity, attention may be called to the harmful effects of certain inorganic compounds in the soil, notably soluble salts of aluminum, which are precipitated, or at least rendered nontoxic, by liming. Also, there are good reasons for believing that long cultivated lands are rather frequently so poor in lime as not to be able to supply the physiological needs of crops with high lime requirements such as clover and alfalfa.

ESTIMATED RATE OF LOSS OF LIME.

At the Rothamsted Experiment Station in England, lysimeter experiments show that 20 pounds of lime carbonate per acre may be leached from the soil in each inch of drainage water. With 15 inches of drainage water, about the average there, the annual loss would be 300 pounds of carbonate of lime per acre. On chalked lands, having as much as 3 percent of carbonate of lime, this loss will reach 1,000 pounds of carbonate of lime annually.

E. Van Alstine reports results of lysimeter experiments by Hanamann in which soils rich in lime lost as much as 2,700 to 3,500 pounds per acre of carbonate in one year. Hall and Miller recorded a loss of 700 to 800 pounds of carbonate of lime in one year without ammonium salts and 1,200 pounds per year with ammonium salts.

In Illinois Bulletin 212, Stewart reports that Hopkins calculated for the gray silt loam on tight clay, 760 pounds carbonate of lime per acre removed annually from 20 inches of soil and 542 pounds under the same conditions from the Odin experimental field.

It is at once evident that the rate of removal depends on several factors such as the amount of lime in the soil, the annual rainfall,

the extent of percolation, the rate of acid formation, and the porosity of the soil.

These facts, together with our knowledge of the large amount of lime found in drainage water generally, supports the conclusion that lime is leached from the soil slowly but constantly until the point is reached where the supply of alkaline bases is insufficient to neutralize the accumulation of acids caused by modern methods in agriculture. Also the supply of lime may become so low as either not to meet the physiological needs of certain crops, or to prevent the solution of toxic inorganic soil constituents.

GROWTH OF THE AGRICULTURAL LIME INDUSTRY.

In the United States, the development of the agricultural lime industry has been very rapid in the last twelve or fifteen years and has extended into new territory where previous to fifteen years ago the liming of soils had never beeen practiced.

Barker, in 1917, stated that five years earlier there was only one company in New York State producing ground limestone for the agricultural trade. In 1917, there were 56 plants operating with a capacity of 675,000 tons annually. This output was based on operating eight months of the year from eight to ten hours daily.

In Volume 1, No. 5, of the Agricultural Lime News Bulletin the geographical production of agricultural lime in the United States is presented. It is shown that while the production in such States as Pennsylvania, Illinois, Michigan, and Ohio is large in the aggregate, the amount produced in proportion to the improved farm land of those States is very small and ranges from less than 10 pounds per acre of calcium oxid in Ohio to only 40 pounds per acre in Pennsylvania. It is stated that the states producing lime average a production of only 11 pounds each per acre and that the needs for lime are approximately 20 times that amount annually.

RATE OF APPLYING LIME.

While it is logical and may be a good practice to apply lime in sufficient quantities to meet fully the lime requirement of the soil and maintain, as far as possible, a neutral soil, such advice is not warranted under all conditions. Recent lime surveys show very large lime requirements over extensive areas. Farmers in those regions cannot afford to apply lime to their land in such large

quantities, as the expense is too great. It therefore becomes a problem of the minimum quantity that may bring profitable returns on the investment in lime. As yet, there are not sufficient experimental data covering this point to make possible a definite statement. Further knowledge relative to the character of acidity and its effect upon different crops is needed in this connection.

Blair, in New Jersey Circular 54, says, "One-half ton of burnt lime or one ton of limestone is often sufficient. On soil not of limestone origin and not limed in five years, 1,500 to 2,000 pounds per acre of burnt lime for general farm crops is a moderate application. On sands and sandy loams, this may be reduced to 1,000 or 1,500 pounds." The more organic matter there is in the soil, the more lime may be applied. In a rotation in which potatoes occur he advises liming after the potato crop sufficient only to bring clover. On low wet lands and mucks 5,000 to 10,000 pounds are sometimes needed.

Stewart in Illinois Bulletin 212 advises for southern Illinois 1 ton of limestone once in three or four years. After the initial acidity has been destroyed, he believes this amount sufficient to keep the soil alkaline or sweet.

In Pennsylvania Bulletin 164, White found the average lime requirement on the limed soils of the State to be 1,749 pounds per acre, while the lime requirement of the unlimed soils averaged 3,105 pounds. In Potter County in the glaciated region 100 percent of the soils were acid and the average lime requirement was 7,928 pounds, while in Lehigh County only 3 percent of the soils were acid and the average lime requirement was only 124 pounds.

MOVEMENT OF LIME IN THE SOIL.

The lateral movement of lime in well drained soils is very small. This is evident from the wide range in lime requirement often found within very short distances. On the experimental plats at the Pennsylvania Agricultural Experiment Station, White reports good clover and alkaline soil on a spot on an ammonium sulfate treated plat and no clover and a very acid soil 18 inches from this spot.

In well-drained soils, the vertical movement of soil moisture by gravity and by capillary rise is usually greater than the lateral movement and it seems probable, therefore, that the vertical movement of lime in soils is generally greater than the lateral movement. In spite of this, the vertical movement of lime is very slow as shown

by lime determinations at different depths in soils that have had lime applied at the surface for a long period.

METHODS OF APPLYING LIME.

To be effective, lime should be as thoroly mixed as possible with the plowed portion of the soil. This is usually most economically done by broadcasting lime on newly plowed land and mixing it with the soil by the disking and harrowing necessary to prepare the seed bed. Most of us adivse against plowing lime down. In theory, a portion of the lime application might be made before plowing and disked into the soil and the remainder applied after plowing as above suggested. There is no evidence, however, showing that this would be economical. The time of application or the season of the year is immaterial and in farm practice it will often be determined by the distribution of farm labor. The place in the crop rotation should be just preceding the crop most responsive to lime, providing it is convenient to apply at that time and the preparation of the land will provide for proper mixing of the lime with the soil. Where this is not possible, it may be applied for a crop earlier in the crop rotation.

While top dressing with lime is not generally advised, it may be justified on land already seeded to clover, especially when the success of the clover will be largely determined by the lime. For top dressing, I believe that finely pulverized limestone may be better than freshly burned lime in spite of frequent statements to the contrary. Freshly burned lime used as a top dressing is subject to puddling, in which case the lime will cake and remain on the surface for a long time.

The old method of spreading lime from small piles distributed over the field by means of shovels is not to be recommended. Such distribution is too uneven to expect the best returns from it. Nothing is better for spreading lime than a lime spreader made for the purpose. One which will provide for a wide range in the rate of application, will not clog, and will spread uniformly, is to be recommended. The lime should be so placed in the field that it will be accessible to the lime spreader and provide for the minimum amount of handling of the lime.

A lime spreader that can be conveniently attached to the rear of a wagon so that the lime may be transferred from the wagon to the spreader as it passes across the field saves much labor in handling the lime. Professor C. A. Mooers of the Tennessee Agricultural

Experiment Station reports that the Holden distributor meets such requirements. It is an end-gate distributor which he reports gives excellent satisfaction.

PURCHASING LIME.

Lime should be purchased from the nearest source of supply, so far as quality, conditions, and prices will justify. Freight charges and cost of cartage are relatively large proportions of the final cost in such bulky, heavy material. Where purchased at a distance, carload lots are advised. This will frequently necessitate cooperation on the part of purchasers. The final basis for determining the cheapest source of lime is to calculate the cost per unit of active material of the different forms and qualities available, laid down on the land of the farmer. Magnesian limestone has thus far not been objected to on the part of the farmers. Limestone containing more than 10 percent of magnesium carbonate is called magnesian limestone. As the percentage approaches 45 percent, it is then called dolomite. Magnesium is found in all soils and is an essential element to plant growth. It has a higher neutralizing power than calcium, the exact ratio of calcium oxid and magnesium oxid being 100 to 140. The magnesium oxid content of lime may, therefore, be multiplied by 1.4 to obtain its relative neutralizing power as compared to calcium oxid. The product should then be added to the calcium oxid content of the lime in question.

Table 1 shows the composition and value of certain forms of lime in Pennsylvania.

TABLE 1.—*Composition, retail price and unit value of pulverized limestone and burnt lime from 1917 to 1919, as determined by the Pennsylvania Department of Agriculture.*

Year.	Material.	No. of samples.	CaO.	MgO.	Retail price per ton.	Lbs. CaO for $1.00.	Cost per unit, cents.
			Percent.	*Percent.*			
1917..	Limestone	21	44.35	4.58	$4.61	216	9.6
	Burnt lime	10	63.07	2.59	6.00	220	9.0
1918..	Limestone	29	46.31	4.32	7.39	139	14.4
	Burnt lime	6	66.08	9.00	7.43	207	9.7
1919..	Limestone	56	49.94	1.89	7.29	143	14.0
	Burnt lime	15	69.42	2.44	9.60	151	13.3

White, in Pennsylvania Station Bulletin 149, says:

The increased cost of the very finely ground limestone, together with the rapidity with which it disappears from the soil as compared with coarser material, leads to the conclusion that an application of material all of which will pass a 10 mesh screen and include all of the fine material incident to such grinding is sufficiently fine for soil improvement if applied somewhat in excess of the immediate need of the soil.

He also presents results of pot experiments with four grades of limestone particles for both high calcium and magnesium limestone compared with equivalent amounts of burnt lime and gives references to other experiments with the fineness of ground limestone.

FINENESS OF GROUND LIMESTONE.

The fineness of pulverized raw limestone is a subject on which there is much disagreement. There are not yet sufficient experimental data and accumulation of facts concerning cost of pulverization to arrive at a definite conclusion. Material finer than 60/100 to 80/100 of an inch in diameter is known to be immediately available. Material coarser than 1/50 of an inch in diameter requires some time to become available. At present, a number of the experiment stations are advising the use of the total product of pulverization that will pass a 10-mesh screen, thus providing for no limestone particles larger than 1/10 of an inch in diameter. In such a product 50 percent or more of the total will usually pass the 60-mesh screen.

Barker, in Bulletin 430 of the New York State station, states that pulverization as fine as cement may add \$0.50 to \$1.50 per ton to the cost. It also necessitates the use of bags, entailing an additional cost of \$1.00 per ton or more. Such fine material is more difficult and more disagreeable to handle than when not quite so fine.

Stewart, of the Illinois station, after four years' results on Newton Experimental Field, found evidence that finely ground limestone was no more effective than the total product from a one-fourth-inch screen which contained both finer material for immediate use and coarser material for durability.

HOME BURNING AND GRINDING.

Where limestone is available on the farm or in the immediate locality, the home burning of limestone should be encouraged where the supply of labor and cheap available fuel is at hand. In the absence of fuel, the pulverization of such stone with portable pul-

verizing machinery should be considered. Work of burning or pulverizing limestone can generally be done at times when farm work is not pressing. The prevalence of farm tractors, together with the various makes of portable pulverizers now on the market, make such home production of agricultural lime feasible and profitable.

LIME NOT A FERTILIZER.

In conclusion let us not forget the old adge that "Lime and lime without manure makes both farm and farmer poor." Lime should be used to correct soil acidity and meet the lime requirement of soil and plants. It can not be expected to take the place of the essential plant food constituents so frequently needed in the soil. After liming, use manure and fertilizers in the usual way, keeping in mind the fact that the returns from these will be greatest where sufficient lime is used.

A COMPARISON OF MAGNESIAN AND NONMAGNESIAN LIMESTONES.[1]

A. W. BLAIR.[2]

Frequent requests for information with reference to the relative value of magnesian and nonmagnesian limestones led to the laying out, in 1908, of four blocks of plats, each block containing 7 twentieth-acre plats, to be devoted to this work. The plan provides for four different 5-year crop rotations in which the two forms of lime are used. The following rotations were adopted:

Rotation.	First year.	Second year.	Third year.	Fourth year.	Fifth year.
1.....	Corn.	Oats.	Wheat.	Timothy and clover.	Timothy and clover.
2.....	Corn.	Potatoes.	Rye.	Timothy and clover.	Timothy and clover.
3.....	Corn.	Potatoes.	Tomatoes.	Lima beans.	Cucumbers.
4.....	Corn.	Oats and peas, millet.	Rye and vetch, rape.	Rye, cowpeas.	Oats and peas, cowpeas.

[1] Presented at the thirteenth annual meeting of the American Society of Agronomy, Springfield, Mass., October 19, 1920.

[2] Professor of agricultural chemistry, Rutgers College and the State University of New Jersey, New Brunswick, N. J.

Thruout the entire period the nonlegume crops have been followed by legume cover crops wherever this has been possible. The plats were so arranged that in each of the four blocks there was a check plat (no limestone) and three plats which received a half ton, 1 ton, and 2 tons of calcium limestone per acre, and three which received the same quantities of magnesian limestone. The limestone was finely ground, being the so-called 200-mesh limestone. The first application was made before planting the corn in 1908 and subsequent applications were made preceding the corn in 1913 and again in 1918.

The soil is a loam or gravelly loam which originally had a lime requirements of about 1,200 to 1,800 pounds per acre.

It has been customary to apply to these plats annually about 300 to 400 pounds of acid phosphate, 100 pounds of muriate of potash, and a nitrogenous fertilizer equivalent to 160 to 200 pounds of nitrate of soda per acre. There have been slight variations in the fertilizer treatment for the different rotations, but the treatment for the seven plats in a given rotation and for a given crop has always been uniform.

Thruout the entire period a careful record has been kept of the crop yields, and with the exception of two crops, tomatoes and cucumbers in rotation No. 3, a complete record has also been kept of the amount of nitrogen recovered in the various crops.

On account of the varied character of the crops and the fact that some were harvested in the ripened state and saved as grain and straw, others as forage crops, and still others like potatoes and tomatoes were weighed as harvested, it is difficult to make a comparison of yields without introducing lengthy tables which are not easily exhibited and explained in a paper of this character.

For this reason it has seemed best to compare the two treatments by means of the total nitrogen recovered in the crops. The amount of nitrogen thus recovered is calculated by multiplying the weight of the crop—dry or field weight according to the method of saving—by the percentage of nitrogen in a sample of the crop, the nitrogen determination being made on a sample comparable to the crop as weighed. With abnormal nitrogen treatment it would be possible so to change the nitrogen content of the plant as to make this method of comparison unfair, but in this experiment the nitrogen treatment was normal and uniform thruout and all the plats yielded normal crops.

The nitrogen yields reported as 5-year averages, 1908–1912 and 1913–1917, inclusive, for the four rotations are shown in Table 1. It should be explained that the low yields for rotation 3 in the first portion of the table are due to the fact that the nitrogen was not calculated for the tomato crop of 1910 and the cucumber crop of 1912.

TABLE 1.—*Total pounds per acre of nitrogen recovered thru the crops of a 5-year rotation.*

FIRST PERIOD, 1908–1912.

Rotation No.	Check (no limestone).	0.5 ton calcium limestone.	0.5 ton magnesian limestone.	1.0 ton calcium limestone.	1 ton magnesian limestone.	2 tons calcium limestone.	2 tons magnesian limestone.
1.........	129.9	135.4	185.2	152.0	184.9	162.1	193.7
2.........	140.6	182.3	169.4	156.0	167.3	178.6	174.3
3.........	63.4	75.8	71.9	75.9	81.0	79.6	80.9
4.........	313.1	384.0	395.5	442.0	424.2	433.1	424.5
Average...	161.8	194.4	205.5	206.5	214.4	213.4	218.4

SECOND PERIOD, 1913–1917.

Rotation No.	Check (no limestone).	0.5 ton calcium limestone.	0.5 ton magnesian limestone.	1.0 ton calcium limestone.	1 ton magnesian limestone.	2 tons calcium limestone.	2 tons magnesian limestone.
1.........	124.8	173.2	195.6	213.4	243.5	226.1	242.3
2.........	165.1	192.3	221.2	233.3	242.2	257.4	239.9
3.........	125.1	150.6	142.0	167.2	162.3	157.0	157.3
4.........	202.4	275.1	349.7	339.4	393.1	416.5	401.7
Average...	154.4	197.8	227.1	238.3	260.3	264.2	260.3

On examining the first section of Table 1, it is found that the average for the four rotations shows a slight advantage in favor of the magnesian limestone as follows:

		Pounds of nitrogen recovered per acre (5 year rotation).
0.5 ton per acre	calcium limestone	194.4
	magnesian limestone	205.5
1.0 ton per acre	calcium limestone	206.5
	magnesian limestone	214.4
2.0 tons per acre	calcium limestone	213.4
	magnesian limestone	218.4

It must be admitted in this connection that the differences in favor of the magnesian limestone are small and also that in some of the individual rotations the figures are reversed.

Attention may be called to the high yields of nitrogen in rotation 4. This is due in part to the fact that two crops were harvested from these plats during four of the five years, and in part to the fact that legume crops were frequently grown in this rotation. It is of further interest to note that the average yield of nitrogen for this rotation was, without exception, more than double the average yield for rotations 1 and 2.

With the exception of the potatoes and tomatoes, the limestone-treated plats, even where the application was only a half ton per acre, have yielded more nitrogen than the check plats. This increase in nitrogen is due in part to a higher percentage of nitrogen in the crops from the treated plats and in part to increased yields. It is believed that the higher percentage of nitrogen in the legume crops from the treated plots can be explained on the ground that liming makes the conditions favorable for the nodule-forming organisms and that with increased nodule formation more nitrogen is stored up in the plant.

The results for the second 5-year period, 1913 to 1917, are given in the second section of Table 1. An examination of the averages for the four rotations shows that for the ½-ton and 1-ton applications the magnesian limestone gave slightly larger yields of nitrogen than the calcium limestone. For the 2-ton application the results are slightly in favor of the calcium limestone.

The corn crop of 1918 begins the third 5-year period, which has not yet been completed. The figures for this crop (Table 2) are of interest in connection with those already reported.

TABLE 2.—*Total nitrogen recovered in the corn crop of 1918 (pounds per acre).*

Rotation No.	Check.	0.5 ton calcium limestone.	0.5 ton magnesium limestone.	1.0 ton calcium limestone	1.0 ton magnesium limestone.	2.0 tons calcium limestone.	2.0 tons magnesium limestone.
1.........	48.3	54.8	60.3	58.5	62.6	57.7	54.8
2.........	55.0	52.3	67.0	63.7	60.0	67.3	69.3
3.........	58.5	68.7	69.9	72.0	70.0	72.0	72.9
4.........	59.4	61.6	63.0	56.6	58.3	66.7	56.5
Average...	55.3	59.3	65.0	62.7	62.7	65.9	63.4

Again taking the averages for the four rotations, it will be noted that with the ½-ton application the magnesian limestone gave a return of 65 pounds of nitrogen per acre as against 59.3 pounds for the calcium limestone. With the 1-ton application the average yields are the same for the two forms of limestone, and with the 2-ton application the calcium limestone yielded 2½ pounds of nitrogen per acre more than the magnesian limestone.

It will thus be observed that the results with the two forms of limestone are very nearly the same whether we compare them by 5-year periods or by the results of a single crop.

Three crops of tomatoes have now been grown on these plats and it is of interest to compare the yields with reference to amount and form of limestone used. These comparisons are shown in Table 3.

It is noteworthy that with the calcium limestone the yields invariably decrease as the application increases from ½ to 2 tons per acre, altho for two out of the three years all of these lime-treated plats show an increase over the check plat. For the third year the check plat gave the highest yield of any.

The yields from the magnesian limestone plats are fairly uniform and do not show any particular tendency either to increase or decrease with increase of limestone. They exceed the yields on the check plats for two out of three years. When the averages are compared, it is found that the yields for two of the three years are practically the same for the calcium as for the magnesian limestone. For the third year the magnesian limestone yielded 400 pounds per acre more than the calcium limestone.

TABLE 3.—*Field weight of marketable tomatoes with different amounts of calcium and magnesian limestone (pounds per acre).*

Treatment.	Yield, pounds per acre.		
	1910.	1915.	1920.
Check	7,720	24,080	18,728
0.5 ton calcium limestone	13,240	28,550	15,034
1.0 ton calcium limestone	11,240	27,860	13,768
2.0 ton calcium limestone	9,960	25,610	9,879
Average	11,480	27,340	12,894
0.5 ton magnesian limestone	11,540	25,454	16,664
1.0 ton magnesian limestone	13,000	27,720	17,747
2.0 ton magnesian limestone	9,620	28,924	16,352
Average	11,387	27,366	16,921

Lime requirement determinations were made on samples of soil from all plats in 1913, 1917, and 1919. In most cases the check plats showed a requirement of about 1,200 to 1,600 pounds of lime (CaO) per acre.

In 1919, about a year after the third application of lime, the plats that received a half ton of calcium limestone per acre showed an average lime requirement of about 675 pounds per acre; the average requirement for the corresponding magnesian limestone plats was 600 pounds per acre. The average requirement for the plats receiving 1 ton of calcium limestone per acre was 250 pounds and for the corresponding magnesian limestone plats 200 pounds per acre. All plats, both calcium and magnesium treated, which received the 2-ton application, were alkaline. It would thus appear that in the matter of satisfying lime requirement there is but slight difference between the two materials.

Also, in 1919, determinations were made of the hydrogen-ion concentration of the same samples used in making the lime requirement determinations. The results, expressed as *pH* values, are shown in Table 4.

TABLE 4.—*Hydrogen-ion concentration, expressed as pH values, of soil from the calcium and magnesian limestone plats.*

Treatment.	Rotation 1.	Rotation 2.	Rotation 3.	Rotation 4.
Check	5.4	5.8	5.5	5.4
0.5 ton calcium limestone	6.1	6.0	6.1	6.0
1.0 ton calcium limestone	6.7	6.5	6.3	6.3
2.0 ton calcium limestone	7.2	7.1	7.1	7.1
0.5 ton magnesian limestone	6.0	6.3	6.2	6.2
1.0 ton magnesian limestone	6.5	6.7	6.5	6.4
2.0 ton magnesian limestone	7.0	6.9	6.9	6.9

These figures also indicate that the difference in neutralizing power of the two forms of lime is slight. It must be borne in mind, however, that these figures do not measure the lime requirement of the soil, but only the hydrogen-ion concentration.

SUMMARY.

1. The results of 11 years of work with the two forms of limestone on four different crop rotations are reported.

2. Using the total amount of nitrogen returned in the crops as a measure, the two forms of limestone give results which are very nearly the same. The magnesian limestone appears to have a slight advantage.

3. Measured by the hydrogen-ion concentration and by determinations of lime requirement of samples of the treated soil, the two limestones also have about the same corrective power.

4. There is no indication of any toxic effect due to the use of the magnesian limestone.

SULFUR SUPPLIED TO THE SOIL IN RAINWATER.[1]

B. D. WILSON.[2]

Some differences of opinion exist concerning the advisability or necessity of applying sulfur to soils in order to increase their productiveness. Data have been presented by investigators showing both beneficial and detrimental effects on the growth of certain plants from its application in one form or another. Whether the stimulative or depressive action, as the case may be, is a direct or an indirect one, or both, is more or less a matter of conjecture at the present time. In considering the relation of sulfur to soils, whether it be from the standpoint of sulfur conservation or from the effects that this constituent may have on bacterial or higher plant activity, the quantity of sulfur supplied to the soil in the rainwater must be taken into account. This fact has been recognized by a number of workers and analyses of the rain falling in many parts of the world have been made to determine its sulfur content. At Ithaca, where the rainwater has been analyzed for a number of years for certain constituents, sulfur has been determined for two years, the results of which are herein reported.

Miller[3] found the rain falling at Rothamsted, England, to contain a yearly average of 17.41 pounds of sulfur (SO_3) to the acre. He reports Gray, working at Lincoln, New Zealand, and Sestini at Catania, Sicily, to have found 14.94 and 20.89 pounds, respectively.

At Leeds, England, Crowther and Ruston (1) report the atmospheric precipitation to be extremely high in sulfur. The rain falling at eleven stations for a period of one year in and near the city contained, on an average, 161.27 pounds SO_3 calculated to the acre basis. At one station near the industrial area of the city the sulfur content was as high as 336 pounds. While most of the sulfur was present in the form of sulfate, appreciable amounts of sulfur dioxid and hydrogen sulfid were always found. At Garforth, 6 miles east of Leeds, these same authors report the annual precipitation of sulfur

[1] Contribution from the Department of Soil Technology of the New York State College of Agriculture at Cornell University. Received for publication January 24, 1921.

[2] Assistant professor of soil technology, New York State College of Agriculture, Cornell University, Ithaca, N. Y.

[3] Reference is to "Literature cited," p. 229.

(SO_3) to be equivalent to 95.68 pounds per acre, about 26 percent of which was found to be present in forms less highly oxidized than sulfates.

Vityn (6) states from analyses of rain collected at eight different places in Russia that the rainwater supplied the soil with considerably more sulfur than was contained in relatively high yields of grain and straw.

Approximately eight months' rain at Mt. Vernon, Iowa, is reported by Peck (3) to contain 8.44 pounds of sulfur (SO_3), while Trieschmann (5) found the rain falling for a slightly longer period at the same place to contain 1.51 pounds.

Stewart (4) finds the rainfall of Urbana, Ill., to supply an acre of soil annually with an average of 45.1 pounds of sulfur. It is reported from observations extending over a period of seven years that the quantity of sulfur brought down in the rainwater depends directly on the amount of precipitation.

The rainwater at Ithaca is collected in a metal rain gauge, which is emptied after each rain or snow, and the water stored until analyzed in glass bottles containing a few drops of mercuric chlorid solution. The gauge is 8 inches in diameter and stands about 9 feet above the ground. As the gauge is located in a field near which there are no factories, and as it is protected from birds by a movable frame extending a little above and beyond the top of the gauge, the water collected is comparatively free from contamination.

The quantity of sulfur found in the rainwater for each of two years is shown in Table 1. It may be seen from this table that the rainfall for the two years reported supplied the soil with an average amount of sulfur equivalent to 26.19 pounds per acre, and that the values for the two years do not differ greatly.

TABLE 1.—*Sulfur in the rainwater at Ithaca, N. Y., between May 1, 1918, and May 1, 1920.*

Period collected.	Rainfall, inches.	Sulfur, p.p.m.	Sulfur, pounds per acre.
1918–1919	30.27	4.06	27.80
1919–1920	24.03	4.52	24.58
Average	27.15	4.29	26.19

The quantity of sulfur reported to be present in the rain falling at each of the several places which have been mentioned is listed in Table 2. An inspection of this table shows that the rainwater col-

lected in the industrial area of England in which Leeds and Garforth are located is highly charged with sulfur-bearing compounds and that a wide variation exists in the amount of this constituent in the rain falling in agricultural regions. It is somewhat striking that the rainwater at Urbana, where there are few factories and which is situated in a State given over very largely to agricultural pursuits, should contain more sulfur than the amount reported to be present in the atmospheric precipitation at Garforth. The supposition has been, and it is perhaps generally true, that the rain falling in industrial centers contains more sulfur than that falling elsewhere. From the figures presented such an assumption may be very misleading, as the quantity of sulfur brought down in the atmospheric precipitation is sometimes larger in agricultural areas than in manufacturing ones. The presence of the relatively large amount of sulfur found in the rainwater at Urbana can probably be accounted for from sources of atmospheric contamination common to most communities, such as the gases evolved from the use of coal by railroads and by heating and electrical power plants.

TABLE 2.—*Quantity of sulfur in the rainwater at places mentioned herein.*

Place.	Period collected.	Average annual rainfall.	Pounds per acre reported yearly.	Pounds per acre as elemental sulfur.
Rothamsted, England (2)	1881–'87	29.95	17.41 SO_3	6.97
Catania, Sicily (2)	1888–'89	18.36	20.89 SO_3	8.37
Lincoln, New Zealand (2)	1884–'88	29.70	14.94 SO_3	5.98
Garforth, England (1)	1906–'09	26.95	95.68 SO_3	38.32
Leeds, England (1)	1907–'08	[a]27.10	161.27 SO_3	64.58
Mt. Vernon, Iowa (3)	1916–'17	17.69	[b]8.44 SO_3	3.38
Mt. Vernon, Iowa (5)	1918–'19	22.25	[b]1.51 SO_3	0.61
Urbana, Ill. (4)	1913–'19	——	45.10 S	45.10
Ithaca, N. Y.	1918–'20	27.15	26.19 S	26.19

[a] Rainfall at Garforth for 1907.
[b] Record for approximately eight months.

Since most of the information concerning the quantity of sulfur in rainwater has been obtained from data resulting from the analyses of the rain falling in or near cities or towns, the application of such data to rural districts is highly speculative. In an attempt to approximate the amount of this element the rain is likely to furnish the soil in any particular section certain factors must be carefully considered, the principal ones being the position of the area in question with reference to railroads, to cities of varying sizes, to the direction of the prevailing winds, and to the sulfur content of the coal used in the region under consideration.

If sulfur is applied to soils for the express purpose of supplying the needs of plants with an essential element, with the thought that it may be a limiting factor in crop production, its application is unnecessary in many localities and is certainly not practical in the vicinity of large industrial cities.

LITERATURE CITED.

1. CROWTHER, CHARLES, and RUSTON, A. G. The nature, distribution and effects upon vegetation of atmospheric impurities in and near an industrial town. *In* Jour. Agr. Sci., 4: 25-55. 1911.
2. MILLER, N. H. J. The amounts of nitrogen as ammonia and as nitric acid and of chlorine in the rain water collected at Rothamsted. *In* Jour. Agr. Sci., 1: 280-303. 1905.
3. PECK, E. L. Nitrogen, chlorine, and sulphates in rain and snow. *In* Chem. News, 116: 283. 1917.
4. STEWART, ROBERT. Sulfur in relation to soil fertility. Ill. Agr. Expt. Sta. Bul. 227. 1920.
5. TRIESCHMANN, J. E. Nitrogen and other compounds in rain and snow. *In* Chem. News, 119: 49. 1919.
6. VITYN, I. A. The quantities of chlorine and sulphur carried into the soil by atmospheric precipitation. *In* Zhur. Optyn. Agron. (Russ. Jour. Expt. Landw.) v. 12, no. 1, p. 20-32. 1911. *Abs. in* Expt. Sta. Rec., 25: 317. 1911.

AGRONOMIC AFFAIRS.

DELAY IN MAY ISSUE.

The long delay in publication of the May issue of the JOURNAL has been due to the printers' strike, which has been in effect since May 1. Naturally considerable time is required to break in new compositors for the setting of technical and tabular matter, but the printers now assure us that our work will be handled promptly and it is hoped that no further delays will occur.

MEMBERSHIP CHANGES.

In the April issue a membership of 636 was reported. Since then 14 new members have been added and 1 lapsed member has been reinstated, while 4 have resigned, making a net gain of 11 and a total membership at this time of 647.

BOOK REVIEW.

THE SOILS AND AGRICULTURE OF THE SOUTHERN STATES. *By Hugh Hammond Bennett.* 399 p., illus. New York, Macmillan & Co., 1921. The United States Bureau of Soils started its systematic classification

and mapping of field soils nearly a quarter of a century ago. The results of this nation-wide survey have been published from time to time and the information is available either in the advance sheets of the Bureau of Soils or in the annual reports of its field operations. A summing up of the work has also been made in a purely technical way in several Departmental bulletins. Nevertheless, neither the trained agronomist nor the student of agriculture, not to mention the farmer, has found it an easy task to correlate the vast amount of accurate agricultural information compiled in the various soil survey reports.

Mr. Bennett's book has been prepared with the idea of making available in a readable form to teacher, student, and farmer alike the available information relative to the soils and agriculture of the eighteen Southern and Southeastern States. While the material has come largely from the publications of the Bureau of Soils, the reader is constantly aware of the fact that the author has had an unlimited stock of personal information to draw upon which was gained thru his years of field work in the survey. This has been a great asset in enabling him to present the material in such an interesting manner.

As might well be expected, the author has laid particular stress on the relation of the soil to crop production. In this connection not only is the adaptation of crops to certain soils emphasized, but at the same time the bearing which the soil has on the system of fertilization is forcefully presented. His discussion of the relation of the soil to the fertilizer requirements is of particular significance because of the recent tendency on the part of certain groups to minimize the soil characteristics in recommending fertilizer treatments.

"The Soils and Agriculture of the Southern States" fills a real need in our agricultural literature. Not only will it be read with interest and profit by the various agricultural workers of the country, but it should also prove of inestimable value as a reference book. Unfortunately it will not receive the attention on the part of the farmers which it deserves. One would hardly dare predict the value that would result to American agriculture if every farmer of the eighteen States covered should acquire the information contained in this volume. Let us hope that this book will prove to be, as the author suggests, "Volume I of a series covering the soils of all sections of the United States and their relation to agriculture."

E. L. WORTHEN.

NOTES AND NEWS.

P. V. Cardon, for the past two years agronomist at the Montana college and station, is now director of the Branch Agricultural College, Cedar, Utah.

C. O. Cromer, formerly assistant agronomist at the Indiana station, is now associate professor of farm crops at Pennsylvania State College.

John W. Gilmore, professor of agronomy in the California college of agriculture and agronomist at the station, is now in Chile as exchange professor from the United States at the University of Chile for the academic year 1921–22.

W. H. Jordan, director of the New York State station at Geneva, N. Y., for the past twenty-five years, has resigned, effective July 1, and was succeeded by R. W. Thatcher, formerly dean of the Minnesota college and director of the station. He has been succeeded in Minnesota by R. C. Coffey, animal husbandman at the Illinois station. U. P. Hedrick has been made vice-director of the New York State station.

David D. Long, in charge of the soil survey at the Georgia college, has resigned to become soil specialist for the Soil Improvement Committee of the Southern Fertilizer Association.

W. J. Morse, plant pathologist at the Maine station, has been appointed director of that station.

Theodore E. Odland, assistant professor of agronomy at the Minnesota college, resigned May 1 to take charge of the crop production work at the West Virginia station.

George R. Quesenberry, formerly in charge of the college farm at the New Mexico college, has been made professor of agronomy in that institution. Donaldson Ryder, formerly assistant agronomist, has resigned to engage in farming, and has been succeeded by W. T. Conway.

Chas. H. Ruzicka, for the past several years superintendent of the Williston (N. Dak.) substation, has been made foreman of the station farm at Fargo, N. Dak.

Dr. John M. Thomas, president of Middlebury College since 1908, has been appointed president of the Pennsylvania college.

A. D. Wilson, director of extension in Minnesota, has resigned to engage in farming and has been succeeded by Frank W. Peck, of the Federal office of farm management.

CONFERENCE OF WESTERN AGRONOMISTS.

A conference of agrononomists of the Rocky Mountain and Pacific Coast States was held in Arizona August 24, 25, and 26. The first day was spent at the University of Arizona at Tucson, and the subsequent days at the experiment stations at Sacaton and Mesa and in taking an auto trip through the principal agricultural portions of the Salt River Valley. The trip from Tucson to Sacaton and Mesa was made by automobile and gave a fine opportunity for observing the general agriculture of that region.

President von KleinSmid of the University of Arizona entertained the members of the conference at luncheon on the 24th.

Papers or discussions were presented before the meeting as follows:

A new method of study of tree transpiration and its effect on the ground water supply, G. E. Smith, University of Arizona.

A small grain thresher for head row work or nursery plats, E. H. Pressley, University of Arizona.

New wheat varieties for the Great Basin, George Stewart, Utah Agricultural College.

The improvement of potatoes by selection within clonal lines, George Stewart, Utah Agricultural College.

Sunflowers for silage, H. N. Vinall, United States Department of Agriculture.

The Federation wheats of California, V. H. Florell, United States Department of Agriculture.

Tillage methods for wheat production on the dry lands of the Columbia River Basin, D. E. Stephens, United States Department of Agriculture.

Root nematodes in their relation to western agronomy, G. H. Godfrey, United States Department of Agriculture.

How best to present the results of experimental work to farmers, Round table discussion.

JOURNAL

OF THE

American Society of Agronomy

Vol. 13. September–October, 1921. Nos. 6, 7

THE INFLUENCE OF WHEAT STRAW ON THE ACCUMULATION OF NITRATES IN THE SOIL.[1]

Herschel Scott.[2]

The extensive application of straw to cropped land in recent years and the observance of certain injurious effects which seemed to indicate nitrogen hunger suggested a study of the effect of straw on the accumulation of nitrates in the soil.

The general problem of organic matter and nitrification has occupied the attention of a large number of investigators and the literature on the subject is extensive.

REVIEW OF LITERATURE.

Winogradsky and Omeliansky (26),[3] working with pure cultures in solution, showed that the activity of the nitrifying organisms is inhibited by the presence of even slight traces of organic matter. The results secured by them are as follows:

Substance.	Percent retarded.	Percent inhibited.
Glucose	0.0250 to 0.05	0.200
Peptone	.0250	.200
NH_3	.0005	.015

According to Percival (19),[3] "The presence of very small amounts of easily oxidized organic compounds is detrimental to the growth and

[1] Contribution No. 18 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication October 16, 1920.

[2] Offered in partial fulfillment of the requirements for the degree of Master of Science at the Kansas State Agricultural College.

[3] Reference is to "Literature cited," p. 257.

activity of both types of nitrifying organisms, the nitrite-forming bacteria being more sensitive in this regard than the nitrate-forming species. On this account the nitrification process does not begin until all the organic material has been fermented by other species of bacteria."

Conn (5) states that "The building of nitrates will not take place in the soil as long as there is any considerable amount of organic material or free ammonia present. The nitrate-forming bacteria will not grow either in the presence of organic material or ammonia. It is not until after decomposition has been completed and practically all the organic compounds used up, that the nitrifying germs can begin to act."

Snyder (23) observes that "The principal organic food of the nitrifying organisms is the organic matter of the soil and it is only when organic matter is incorporated with the soil that it can serve as food for the nitrifying organisms. In the presence of large amounts of organic matter, as in a manure pile, nitrification does not take place. It occurs only when organic matter is largely diluted with soil."

Pitchard (22) found that "Increasing the quantity of organic nitrogen from 1 to 3 grams per kilogram of soil was clearly unfavorable to nitrification. Not only the relative proportions, but also the absolute quantities, of nitric nitrogen decreased as the amount of organic matter increased."

Withers and Fraps (27) studied the nitrifying power and humus content of a number of typical North Carolina soils. They found the greatest nitrifying power in the soil containing the highest percentage of humus, in this case 2.86, and state that most of the soils high in humus are high in nitrifying power. The addition of 3.22 percent of dried barnyard manure to the soil in three cases hindered nitrification during four or five weeks, and in a fourth case nitrification did not proceed vigorously.

Löhnis (15) showed that where soil extract is inoculated with fresh soil, nitrification is not inhibited even when enough organic matter is present to enable denitrifying organisms to grow.

Karpinsky and Niklewsky (12) have shown that, when used in mixed cultures, various organic compounds in low concentration clearly favor nitrification, and that humus-rich soil nitrifies more rapidly than humus-poor soil.

Coleman (4) found that in both pure and mixed cultures, dextrose, cane sugar, glycerine, and lactose in small quantities favor nitrification, and that an amount of dextrose found inhibitive in solution was not inhibitive in sand cultures.

Stevens and Withers (24) found that nitrifications with pure and mixed cultures is inhibited less by organic matter such as peptone. cottonseed meal, and cow manure in soils than it is in solutions, and state that "organic matter even to a large amount, as considered agriculturally, is not necessarily inimical to the functioning of the nitrifying organism in the field." The authors also present data showing that where cow manure was added to soil at rates varying from 1 ton to 160 tons per acre, good nitrification occurred in all cases, and organic matter was still present at the end of the period. The rate of nitrification was inversely proportional to the amount of manure added.

Potter and Snyder (21) found, in pot cultures, a striking decrease in amount of nitrate nitrogen as increasing amounts of manure were added to the soil.

Hill (9) found that the addition of 0.6 percent straw, 0.44 percent clover, 0.44 percent soybeans, or 0.22 percent blue grass to a soil under greenhouse conditions increased nitrification. The addition of 0.3 percent paper, however, to a soil under similar conditions did not increase nitrification except after a long period of incubation. He cites Lenmerman and Tazenke (14) to the effect that a slight loss of nitrogen occurs when green manure is added to a sandy soil, and states that these authors believe that the crude fiber in green manures is indirectly proportional to the soluble nitrogen. This he suggests is perhaps the reason for the common belief that straw decreases the nitrogen in the soil.

Pfeiffer (20) noted a harmful effect from the application of straw.

Bredemann (1) found that the addition of organic matter, such as hay and sugar, produced a harmful effect the first year, but a beneficial effect was noted the next year.

Engberding (6) found that the addition of straw and sugar to the soil at first increased and later decreased the bacteria in the soil. The ammonifying and nitrogen fixing groups were increased and the nitrifying group decreased.

Frankfurt and Duschechkin (7) found that green manure under field conditions caused a diminution of nitrate content of the soil. Both legumes and non-legumes showed this effect.

Warrington (25) states that richness of the soil in organic matter, the presence of $CaCO_3$ or some other base, aeration of the soil, the presence of a certain proportion of water, and a summer temperature are the conditions recognized as most favorable to nitrification. On the other hand, the presence of fresh organic matter or the growth of

molds was known to be injurious. He also describes experiments showing that soil in solution containing nitrates and sugar exercises an energetic denitrifying action, and cites as a well established principle that the presence of oxidizable organic matter is an indispensable requisite for the deoxidation of nitrates.

McBeth and Wright (17), studying the factors limiting nitrification, report that 2 percent of glucose and 2 percent of starch disappeared from soil in less than seven days. Cellulose disappeared more slowly. The addition of glucose and starch caused a rapid disappearance of nitrates from eastern and western soils; with cellulose the disappearance was less rapid. Two percent of fresh horse manure caused only a partial disappearance of soil nitrates. After seven days in eastern soil and twenty-one days in western soil, nitrification became active, causing an increase in nitrates. Nitrification took place rapidly in rotted manure. The addition of 5 percent cellulose to the manure caused rapid denitrification.

Clark and Adams (3) added sugar, molasses, butyric acid, alcohol, and filtered wool-scouring waste in slowly increasing amounts to a solution in which the nitrogen content was constant. When the ratio of carbon to nitrogen remained low, active nitrification occurred. Where nitrification was checked by the large amounts of carbon applied, it did not again become active until the ratio of carbon to nitrogen was considerably reduced. Where nitrification had been checked but not entirely stopped by the carbon, it was reestablished by increasing the amount of nitrogen in the liquid and keeping the carbon constant, i.e., by reducing the carbon-nitrogen ratio. Where nitrogen as NH_4Cl was added to the liquid, nitrification was not checked by carbonaceous bodies, even when very large amounts were added.

According to the work of Greaves and Carter (8) the application of manure, even so large an amount as 25 tons per acre, produces a very great increase in the nitrifying powers of the soil. The authors state that there is no indication that denitrification occurs in the presence of the largest quantities of organic matter applied in this experiment.

Hiltner and Peters (10) found that the growth of oats was retarded by the application of lupine straw. Lupines were not affected. The second year after the application the growth of oats was greater after the lupine straw than after oats. The increase in yield was about 50 percent, so that the net effect of the lupine straw for the first and second years was beneficial. Where oats followed oats the application of straw resulted in a loss the first year and a gain of only about 19 percent the second year, making a net loss for the two years.

Chirikov and Shmuk (2), studying the influence of moisture and increasing amounts of straw on the progress of denitrification in sandy loam soil with the moisture content remaining constant, found that the yield of oats decreased with increasing amounts of straw. The addition of $CaCO_3$ with the straw reduced to an appreciable extent the injurious effect of the latter but did not wholly overcome it. The diminished growth resulting from the application of these substances was not due to denitrification in a strict sense but to the fact that the nitrates in the soil were converted into albuminoid compounds which are less assimilable by green plants than are nitrates.

Niklewsky (18) conducted pot experiments with oats in a sandy loess soil deficient in plant food. Straw was found to have an unfavorable influence on the utilization of $(NH_4)_2SO_4$ with low concentrations, and a favorable influence with high concentrations. Straw hastened the diffusion of $NaNO_3$ in the soil and had a favorable influence on its utilization with low concentrations.

Wright (28) showed that where such substances as straw and fresh manure, cellulose, glucose, and starch were added to soils the nitrate nitrogen was reduced and the process of nitrification was inhibited until decomposition was well advanced.

Jensen (11), studying the relation of nitrification to field factors, found no evident relation between the variation in nitrates and in temperature, whether the mean maximum, mean minimum, or general mean temperature was considered.

King and Whitson (13) compared the rate of nitrification at constant temperatures of 35° F., 48° F., 68° F., and 90° F., and found that the rate of nitrification at 90° was 6.33 times more rapid than at 35° F., and at 68° about twice as rapid as at 48°.

Lyon and Bizzell (16) found that in unplanted soil nitrates usually increased in the spring with the rise in temperature. After midsummer there was little apparent relation between temperature and nitrate content until late autumn. In the case of cropped soil no consistent relation between nitrate content and temperature was observable during midsummer.

EXPERIMENTAL DATA.

In the present study observations were made both on soils kept in jars in the greenhouse and on soils in the field. All nitrate data reported were obtained by the phenoldisulfuric acid colorimetric method of analysis. Parallel determinations were made from time to

time, using the aluminum reduction method on portions of the same filtrate. The results from the two methods were found to be in close agreement.

GREENHOUSE INVESTIGATIONS.

For the greenhouse work twenty-five 4-gallon jars were used. These jars were filled with a thoroly pulverized silt loam soil, which was made up to optimum moisture content.

Five of the jars were used as checks and received no treatment other than the addition of water required to maintain the moisture content at the optimum. Finely cut wheat straw was added at the rate of 1 percent to the soil in ten jars. Five of these received in addition to the straw 0.1 percent of $(NH_4)_2SO_4$. Wheat straw was added at the rate of 0.5 percent to the soil in ten remaining jars. Ammonium sulfate was also added to half of these at the rate of 0.1 percent.

This arrangement provided five jars of each treatment, as follows:

Nos. 1 to 5—No treatment.
Nos. 6 to 10—1 percent wheat straw.
Nos. 11 to 15—1 percent wheat straw and 0.1 percent $(NH_4)_2SO_4$.
Nos. 16 to 20—0.5 percent wheat straw.
Nos. 21 to 25—0.5 percent wheat straw and 0.1 percent $(NH_4)_2SO_4$.

Nitrates in the soil were determined at the beginning of the test and on a sample from each jar at 2, 4, 6, 8, 10, 12, 16, 20, 24, 28, 32, 36, and 48 weeks thereafter. The soil was thoroly stirred and the moisture content made up to optimum each week. A second addition of 0.1 percent of $(NH_4)_2SO_4$ was made to those jars receiving that treatment at the end of four weeks and a third addition at the end of eight weeks.

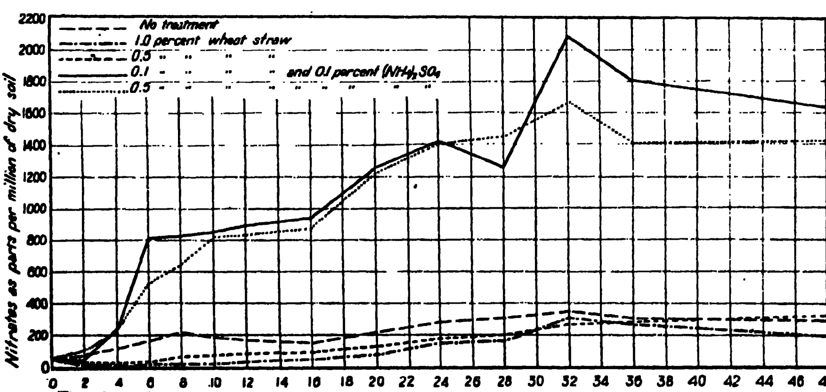


FIG. 9. Graph showing effect of application of straw and of straw and ammonium sulfate on nitrate accumulation in soils.

A tube was used in sampling. By this means a core of soil was taken to the depth of the jar. Duplicate determinations were made on each sample, furnishing an average of 10 determinations on each of the five soil treatments. These results are presented in Table 1 and graphically in figure 9.

TABLE 1.—*Effect of application of straw and of straw and ammonium sulfate on nitrate accumulation in soils under greenhouse conditions, shown as nitrates in parts per million of dry soil.*

Treatment.	Time in weeks.						
	0	2	4	6	8	10	12
No treatment	55.6	79.0	117.2	160.1	217.6	180.8	169.0
1 percent straw	55.6	11.6	4.2	11.6	15.2	14.5	30.0
1 percent straw and 0.1 percent $(NH_4)_2SO_4$	55.6	48.9	237.0	808.3	822.0	842.0	887.0
0.5 percent straw	55.6	23.4	21.7	36.7	68.5	77.0	80.0
0.5 percent straw and 0.1 percent $(NH_4)_2SO_4$	55.6	100.0	228.0	533.4	646.0	812.0	820.0
	16	20	24	28	32	36	48
No treatment	152.0	207.5	293.0	309.1	352.2	313.6	292.0
1 percent straw	40.5	71.6	149.5	167.9	310.6	270.6	199.8
1 percent straw and 0.1 percent $(NH_4)_2SO_4$	936.5	1,240.2	1,422.0	1,265.0	2,084.0	1,809.4	1,635.0
0.5 percent straw	86.9	122.7	180.2	202.0	276.2	285.0	322.0
0.5 percent straw and 0.1 percent $(NH_4)_2SO_4$	869.0	1,219.8	1,413.6	1,455.0	1,668.0	1,407.2	1,423.0

As indicated in Table 1 and in figure 9, the addition of 1 percent and 0.5 percent wheat straw reduced the nitrate content as compared with the check, the reduction being greater for the larger amount of straw. The disappearance of nitrates in the soil to which straw had been added was marked during the first two weeks, and the deficiency continued in a lesser degree during the third and fourth weeks, after which recovery began. At the end of eight weeks the nitrate content of the soil to which 0.5 percent straw had been added reached the original content, while the soil to which 1 percent straw had been added required 18 weeks to regain its original quantity of nitrate.

The nitrate content of the soil to which 0.5 percent straw had been added rose steadily until the end of the experiment, when it slightly surpassed that of the untreated soil, which had dropped during the last 12 weeks.

The nitrate content of the soil to which 1 percent straw had been added remained well below that of both the untreated soil and that to

which 0.5 percent straw had been added except in one instance, where it went above the latter.

The soil to which both straw and $(NH_4)_2SO_4$ had been added suffered a slight loss of nitrates the first two weeks but recovered quickly. By the end of the sixth week it had reached a concentration of 800 parts per million and a maximum concentration of nearly 2,100 parts per million at the end of the 32d week, as compared with a maximum of only about 350 for the untreated and 310 for the soil with straw alone.

Similar results were secured when $(NH_4)_2SO_4$ was added with 0.5 percent of straw.

FIELD EXPERIMENTS.

The field work consisted of comparing the effects on the development of nitrates, the moisture content of the soil, and soil temperature of different amounts of straw applied in two different ways both to an uncropped soil and as a top dressing on wheat.

The soil used is known as the Derby silt loam. Samples for nitrate determinations were secured early in the fall, early in the spring, and at approximately semimonthly intervals until October of the following year. Samples were taken of the following depths: 0 to 6 inches; 7 to 12 inches; 13 to 24 inches; and 25 to 36 inches. Composite samples consisting of two or more cores from each plat were used.

STRAW APPLIED AS A TOP DRESSING ON WHEAT.

This experiment was begun in the fall of 1915. Twelve plats arranged in groups of three each (fig. 10) according to treatment the previous year were used. Plats 1, 2, and 3 had been cultivated to a depth of 3 inches during the summer of 1915. On plats 4, 5, and 6 weeds had been allowed to grow. Plats 7, 8, and 9 had been kept free from all vegetation but had not been cultivated. Plats 10, 11, and 12 had been cultivated to a depth of 6 inches. The different treatments during 1915 had caused marked differences in the nitrate content of the different plats at seeding time, as shown in column 2 of Table 2.

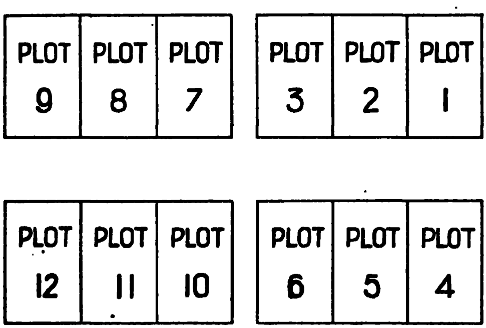


FIG. 10. Arrangement of plats used to determine the effect of straw applied as a top dressing on wheat in the fall of 1915.

On plats 1, 4, 7, and 10 straw at the rate of 4 tons per acre was applied in November, 1915. On plats 2, 5, 8, and 11 straw at the rate of 2 tons per acre was applied in November, 1915. The other plats were used as check plats, no straw being applied.

A marked difference in the growth of the wheat was apparent early in the spring. This difference persisted to the time of harvest. The plats without straw made the best growth, the plants being uniformly vigorous and of a good green color. The wheat top-dressed at the rate of 2 tons per acre made a fairly good growth but was unequal to the check plats. The growth was very much reduced on the plats to which 4 tons of straw had been applied. The plants were noticeably yellow in color and lacking in vigor. These relations were especially pronounced on plats 4, 5, and 6, where the nitrate content at seeding time was very low, and were much less apparent on plats 10, 11, and 12, where the nitrate content was high at seeding time. The strawed plots of each group were from a week to ten days later in heading than were the check plats, and remained green after the latter were ripe. This may be attributed to the larger percentage of moisture present in the soil in the former at harvest time. Excepting plats 10, 11, and 12, which were highest in nitrates at seeding time, the check plats or those to which no straw was applied produced the best yield. The straw appeared to have little effect on the yield of plats 11 and 12 where the nitrates at seeding time were high, indicating that the straw reduced the yield on the other plats by reducing nitrification. This conclusion is strengthened by the appearance of the plants in the spring and their growth during the summer.

TABLE 2.—*Effect of straw applied as a top dressing to wheat in the fall.*

Plat No.	Nitrates at seeding, parts per million.	Tons of straw per acre.	Yield.		Nitrates at harvest, parts per million.	Percent moisture in surface 12 inches at harvest.
			Grain, bus. per acre.	Straw, tons per acre.		
1	172.5	4	17.4	2.70	76.0	29.0
2	172.5	2	16.4	2.44	51.5	29.0
3	172.5	None	29.2	3.80	81.1	19.7
4	5.2	4	9.6	.58	26.7	28.2
5	5.2	2	13.5	.58	31.0	27.2
6	5.2	None	24.2	1.16	59.9	19.0
7	130.1	4	16.4	3.13	64.8	26.5
8	130.1	2	17.4	2.84	87.1	27.2
9	130.1	None	23.7	4.38	91.6	25.0
10	253.5	4	33.8	3.54	58.9	26.5
11	253.5	2	28.0	3.34	62.4	29.7
12	253.5	None	30.0	3.80	66.3	25.0

The treatments, the yields of grain and straw per acre, the nitrates at seeding time and at harvest, and the percentage of moisture in the surface fóot of soil at harvest are given in Table 2.

THE EFFECT OF STRAW ON NITRIFICATION IN UNCROPPED SOIL.

In this experiment straw was applied in two different ways and at two different rates to plats which had been treated alike the previous year, i.e., in 1915. On plats 1, 4, and 7 straw was applied at the rate of 4 tons per acre in November, 1915, and worked into the surface 6 inches. On plats 9, 12, and 15 straw was applied at the rate of 4 tons per acre in November, 1915, as a top dressing. On plats 2, 5, and 8 straw was applied at the rate of 2 tons per acre in November, 1915, and worked into the surface 6 inches. On plats 10, 13, and 16 straw was applied at the rate of 2 tons per acre in November, 1915, as a top dressing. The remaining plats (plats 3, 6, 11, and 14) were left untreated for comparison. Plats 1, 2, and 3 were cultivated during the spring and summer of 1916. Plats 4, 5, 6, 7, and 8 were scraped during the spring and summer of 1916. The weeds on the remaining plats were pulled during the season of 1916. The plats were 6 feet by 10 feet and were separated by 2-foot alleys. The plats as a whole joined those on which the effect of straw as a top dressing was studied, being separated from them by a 5-foot alley. The arrangement of the plats is shown in figure 11.

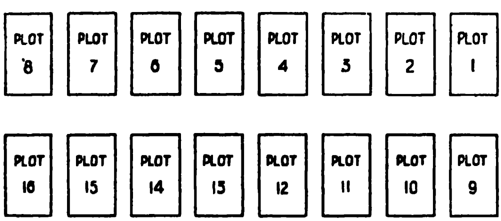


FIG. 11. Arrangement of plats for the study of the effect of straw on un-cropped land.

The average nitrate content to a depth of 3 feet of all plats, expressed as parts per million at the time of applying the straw in the fall, in the spring, and at intervals during the following season, is given in Table 3 and summarized in Table 4. The nitrate content of the surface 6 inches of soil is expressed graphically in figures 12, 13, 14, 15, and 16.

TABLE 3.—*Effect of application of straw on the nitrate content of the soil to a depth of 3 feet.*

Plat No.	Straw applied, tons per acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil.							
					Nov. 29, 1915.	Apr. 5, 1916.	Apr. 18, 1916.	May 1, 1916.	May 15, 1916.	May 30, 1916.	June 15, 1916.	June 28, 1916.
1	4	Worked in	Cultivated	0–6	69.4	57.0	36.9	19.5	14.9	20.1	52.2	43.0
				7–12	62.0	79.0	77.5	52.8	27.5	20.6	65.0	26.3
				13–24	46.1	49.0		36.6		36.0		22.7
				25–36	13.8	26.6		18.3		15.1		31.5
4	4	do	Scraped	0–6	80.4	31.0	53.9	34.0	17.3	22.0	37.2	96.0
				7–12	65.9	75.8	98.0	68.0	21.5	43.5	38.4	102.5
				13–24	30.7	60.1		57.3		72.6		57.0
				25–36	15.6	41.2		37.8		42.0		49.0
7	4	do	do	0–6	75.6	34.4	34.7	35.7	26.2	31.3	26.3	109.5
				7–12	73.7	68.1	73.2	62.4	39.3	44.2	39.7	80.4
				13–24	58.1	55.1		55.2		63.3		62.2
				25–36	22.1	36.9		28.6		32.0		33.2
2	2	do	Cultivated	0–6	43.5	41.4	33.2	30.3	22.4	25.6	39.0	50.2
				7–12	34.6	50.0	46.1	43.5	39.3	37.6	39.0	50.2
				13–24	25.0	34.4		29.0		36.3		42.5
				25–36	14.3	25.4		20.3		13.3		41.2
5	2	do	Scraped	0–6	75.4	97.0	43.6	44.6	29.5	49.0	43.5	69.[illegible]
				7–12	70.5	109.5	75.2	85.8	47.0	60.2	47.0	57.6
				13–24	31.5	60.4		53.6		50.0		43.5
				25–36	15.3	31.2		17.1		29.0		30.3
8	2	do	do	0–6	68.4	62.3	60.6	50.3	19.6	25.3	19.2	91.0
				7–12	57.7	75.1	109.5	87.3	56.0	50.3	39.0	75.4
				13–24	26.3	47.7		46.2		45.0		50.0
				25–36	15.6	33.2		25.9		29.7		29.5

TABLE 3.—*Effect of application of straw on the nitrate content of the soil to a depth of 3 feet (Continued).*

Plat No.	Straw applied, tons per acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil.							
					Nov. 29, 1915.	Apr. 5, 1916.	Apr. 18, 1916.	May 1, 1916.	May 15, 1916.	May 30, 1916.	June 15, 1916.	June 28, 1916.
9	4	Top dressing	Weeds pulled	0–6	56.8	42.2	32.5	26.4	15.6	11.9	21.8	13.0
				7–12	51.2	57.1	45.5	42.2	22.0	13.3	38.0	16.3
				13–24	34.1	42.3		39.0		21.8		12.0
				25–36	10.2	25.9		28.2		32.0		20.5
12	4	do	do	0–6	76.0	41.5	50.7	33.2	20.4	19.7	12.8	13.1
				7–12	65.3	55.0	80.0	65.1	26.2	22.3	12.4	15.6
				13–24	26.5	41.0		61.1		20.6		18.2
				25–36	9.5	21.0		27.0		43.0		32.3
15	4	do	do	0–6	69.1	89.6	54.6	27.1	12.9	17.3	22.0	11.5
				7–12	64.0	93.0	71.8	62.0	16.0	19.0	21.5	10.9
				13–24	33.1	46.4		55.3		14.6		6.6
				25–36	16.7	22.0		34.5		14.4		16.0
10	2	do	do	0–6	57.2	44.2	77.0	63.0	16.5	20.3	19.5	35.6
				7–12	50.6	59.1	63.2	65.6	13.1	22.3	19.2	20.2
				13–24	25.1	37.4		39.5		38.2		31.0
				25–36	9.8	25.0		24.0		32.0		36.3
13	2	do	do	0–6	114.5	104.0	88.4	44.2	20.8	16.5	12.6	15.0
				7–12	71.8	84.6	124.7	95.0	21.3	38.0	27.0	12.3
				13–24	24.1	50.1		54.3		47.1		24.2
				25–36	10.5	22.0		20.7		31.5		42.5
16	2	do	do	0–6	62.7	76.8	56.8	67.8	20.1	16.3	23.4	17.8
				7–12	58.4	76.1	87.2	92.4	26.3	46.5	12.8	19.9
				13–24	28.0	38.5		50.8		51.0		28.7
				25–36	14.8	28.2		23.8		31.1		32.0

TABLE 3.—*Effect of application of straw on the nitrate content of the soil to a depth of 3 feet (Continued).*

Plat No.	Straw applied, tons per. acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil.							
					Nov. 29, 1915.	Apr. 5, 1916.	Apr. 18, 1916.	May 1, 1916.	May 15, 1916.	May 30, 1916.	June 15, 1916.	June 28, 1916.
3	None		Cultivated	0–6	40.8	74.2	81.5	63.6	57.2	32.6	43.5	51.0
				7–12	39.1	57.0	69.2	61.6	94.2	54.0	52.0	48.0
				13–24	34.3	47.7		48.0		35.8		63.6
				25–36	18.4	30.3		27.6		31.1		50.2
6	do		Scraped	0–6	45.1	107.0	99.0	80.6	121.0	89.6	50.2	112.0
				7–12	41.0	73.8	82.8	85.0	104.0	98.4	33.0	78.2
				13–24	25.3	49.0		41.2		60.1		84.7
				25–36	14.7	15.2		31.7		35.0		31.3
11	do		do	0–6	53.0	75.2	112.8	84.0	25.0	50.4	97.0	95.6
				7–12	48.7	56.0	80.8	48.8	60.2	90.0	79.4	91.0
				13–24	35.3	36.7		39.3		48.5		50.0
				25–36	15.3	25.0		24.0		31.0		24.0
14	do		do	0–6	82.6	118.0	98.4	89.8	90.4	60.6	79.4	123.0
				7–12	63.8	96.6	89.0	82.2	130.0	63.2	61.0	102.0
				13–24	36.9	41.5		51.6		41.0		41.
				25–36	14.3	29.7		23.9				20.6

TABLE 3. *Effect of application of straw on the nitrate content of the soil to a depth of 3 feet (Continued).*

Plat No.	Straw applied, tons per acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil.						
					July 12, 1916.	July 24, 1916.	Aug. 7, 1916.	Aug. 21, 1916.	Sept. 4, 1916.	Sept. 18, 1916.	Oct. 6, 1916.
1	4	Worked in	Cultivated	0– 6	59.3	82.8	101.0	109.4	96.6	66.4	118.0
				7–12	38.5	59.0	53.3	63.6	54.0	131.7	101.0
				13–24		44.0		34.9			59.0
				25–36		38.5		30.1			38.8
4	4	do	Scraped	0– 6	65.4	100.0	181.5	180.0	194.3	229.0	196.0
				7–12	62.2	34.5	83.6	70.1	71.7	115.0	145.0
				13–24		35.0		80.0			100.0
				25–36		20.1		33.7			53.4
7	4	do	do	0– 6	71.6	136.0	152.0	135.0	139.4	107.0	218.0
				7–12	49.8	45.3	71.7	70.8	72.8	68.6	113.5
				13–24		39.8		57.0			61.4
				25–36		34.0		28.6			42.4
2	2	do	Cultivated	0– 6	59.8	102.5	93.0	101.6	112.3	41.6	97.6
				7–12	41.0	57.4	49.0	51.8	43.0	77.6	101.0
				13–24		19.9		50.5			52.2
				25–36		18.8		37.0			38.8
5	2	do	Scraped	0– 6	86.0	103.0	181.5	189.0	195.0	229.0	191.0
				7–12	65.6	49.5	87.0	93.2	69.7	129.2	108.0
				13–24		31.5		71.7			72.2
				25–36		25.0		29.9			49.7
8	2	do	do	0– 6	105.0	134.0	134.0	141.5	90.7	256.0	165.0
				7–12	74.7	69.0	65.0	45.5	57.0	112.7	96.0
				13–24		39.5		33.2			64.0
				25–36		34.5		30.0			52.0

TABLE 3. *Effect of application of straw on the nitrate content of the soil to a depth of 3 feet (Continued).*

Plat No.	Straw applied, tons per acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil. July 12, 1916.	July 24, 1916.	Aug. 7, 1916.	Aug. 21, 1916.	Sept. 4, 1916.	Sept. 18, 1916.	Oct. 6, 1916.
9	4	Top dressing	Weeds pulled	0–6	34.9	49.5	66.8	67.6	37.7	40.9	44.8
				7–12	13.5	22.7	30.5	14.7	18.7	34.0	28.4
				13–24		11.8		13.5			19.2
				25–36		16.5		12.0			24.3
12	4	do	do	0–6	31.5	36.0	67.0	48.5	62.8	73.2	49.8
				7–12	21.0	28.7	33.5	25.6	30.5	67.2	28.4
				13–24		11.6		30.1			25.9
				25–36		18.4		54.8			27.9
15	4	do	do	0–6	24.0	35.8	38.0	60.5	35.9	46.8	36.3
				7–12	14.0	19.0	19.1	21.8	18.4	42.8	31.5
				13–24		17.5		12.8			28.0
				25–36		25.0		15.6			24.6
10	2	do	do	0–6	27.0	40.3	92.0	80.6	57.0	46.8	73.0
				7–12	15.5	17.0	36.5	23.6	32.4	59.8	55.6
				13–24		21.2		22.7			32.8
				25–36		17.2		32.2			31.3
13	2	do	do	0–6	37.0	37.0	76.0	82.4	77.8	94.0	145.0
				7–12	37.0	24.0	40.5	31.6	27.0	83.6	82..
				13–24		12.8		25.3			45.5
				25–36		11.2		38.0			54.0
16	2	do	do	0–6	38.0	44.7	76.0	83.8	65.8	79.5	179.0
				7–12	43.0	23.6	39.5	39.0	46.0	54.0	87.2
				13–24		27.0		47.2			60.3
				25–36		16.0		39.5			47.2

TABLE 3. *Effect of application of straw on the nitrate content of the soil to a depth of 3 feet (Continued).*

Plat No.	Straw applied, tons per acre.	Manner of applying straw.	Treatment in 1916.	Depth of sample, inches.	Nitrates, parts per million of dry soil.						
					July 12, 1916.	July 24, 1916.	Aug. 7, 1916.	Aug. 21, 1916.	Sept. 4, 1916.	Sept. 18, 1916.	Oct. 6, 1916.
3	None		Cultivated	0–6	46.5	84.0	70.0	94.4	117.8	63.6	97.4
				7–12	21.8	48.5	37.0	49.2	68.4	105.5	100.0
				13–24		39.5		33.8			56.8
				25–36		31.7		30.3			56.6
6	do		Scraped	0–6	81.0	134.0	184.0	309.0	151.0	134.0	172.0
				7–12	69.5	54.2	72.6	97.0	88.6	65.0	122.0
				13–24		35.0		70.8			86.0
				25–36		21.5		41.8			49.7
11	do		do	0–6	188.5	177.0	180.0	141.5	126.7	85.2	147.5
				7–12	75.8	70.0	70.4	128.0	100.0	103.5	98.0
				13–24		37.0		77.0			51.0
				25–36		31.3		26.2			44.8
14	do		do	0–6	143.5	142.5	194.5	242.0	172.0	250.0	302.0
				7–12	106.5	79.6	80.2	101.0	99.3	156.5	165.0
				13–24		45.8		64.0			77.2
				25–36		23.7		32.2			53.8

TABLE 4.—*Effect of application of straw on the nitrate content of the upper 6 inches of soil.*

Plat No.	Treatment.	Nitrates expressed as parts per million.							
		Nov. 29, 1915.	Apr. 5, 1916.	Apr. 18, 1916.	May 1, 1916.	May 15, 1916.	May 30, 1916.	June 15, 1916.	June 28, 1916.
1	4 tons straw[a]	69.5	57.0	36.9	19.5	14.9	20.1	52.0	43.0
2	2 tons straw[a]	43.9	41.4	33.2	30.3	22.4	25.6	39.0	50.2
3	None[a]	40.8	74.2	81.5	63.6	57.2	32.6	43.5	51.0
4 and 7	4 tons straw[b]	78.0	32.7	44.3	34.8	21.7	26.6	31.7	102.7
5 and 8	2 tons straw[b]	71.9	79.6	53.1	47.4	24.5	37.2	31.3	80.1
6, 11 and 14	None[b]	56.4	101.9	102.3	83.7	89.3	72.5	69.2	110.6
9, 12 and 15	4 tons straw[c]	67.3	57.5	45.9	28.9	16.3	16.3	18.8	12.5
10, 13 and 16	2 tons straw[c]	77.9	75.0	74.0	58.6	19.1	17.7	18.5	22.8
6, 11 and 14	None[c]	56.4	101.9	103.3	83.7	89.3	72.5	69.2	110.6

Plat No.	Treatment.	Nitrates expressed as parts per million.						
		July 12, 1916.	July 24, 1916.	Aug. 7, 1916.	Aug. 21, 1916.	Sept. 4, 1916.	Sept. 18, 1916.	Oct. 6, 1916.
1	4 tons straw[a]	59.3	82.8	101.0	109.2	96.6	66.4	118.0
2	2 tons straw[a]	59.8	102.5	93.0	101.6	112.3	41.6	97.6
3	None[a]	46.5	84.0	70.0	94.4	117.8	63.6	97.4
4 and 7	4 tons straw[b]	68.5	110.0	166.5	157.5	166.9	169.5	207.0
5 and 8	2 tons straw[b]	95.5	118.0	157.7	165.2	142.8	242.5	178.0
6, 11 and 14	None[b]	123.5	146.8	185.5	191.7	150.0	150.5	155.0
9, 12 and 15	4 tons straw[c]	30.1	40.4	57.2	58.8	45.4	53.5	43.6
10, 13 and 16	2 tons straw[c]	30.6	40.6	81.3	82.2	66.4	73.4	132.0
6, 11 and 14	None[c]	123.5	146.8	185.5	191.7	150.0	150.5	155.4

[a] Straw worked in, in the fall; ground cultivated during following season.
[b] Straw worked in, in the fall; weeds removed by scraping during the following season.
[c] Straw applied as a top dressing in the fall; weeds pulled during the following season.

The most marked effect of the straw no matter how applied was to reduce the nitrate content the following spring. The difference between the strawed plats and the checks was especially marked when the straw was applied as a top dressing. Where the straw had been

worked into the soil and the ground was cultivated the following summer, the nitrate content of the strawed plats, after about June 1, was nearly equal to and at times exceeded that of the check plats. The same tendency was observed on the plats which were scraped, but in this case the increase in nitrates after about June 1 was much greater, the total amount at the end of the season being nearly twice as much as in the cultivated plats otherwise treated the same.

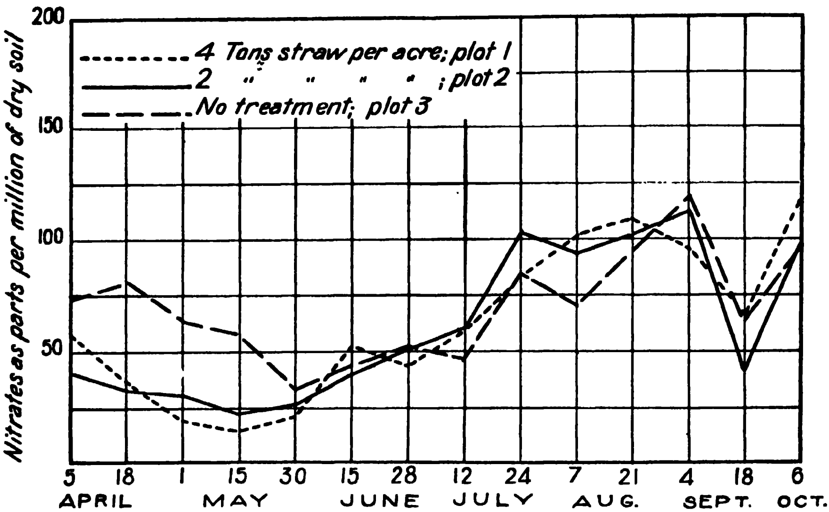


FIG. 12. Graph showing effect on nitrates in the surface soil of straw worked into the ground (Ground cultivated during the following season).

Four tons of straw, when applied as a top dressing, had a greater inhibiting effect than the 2-ton rate, but the effect was not very different when the straw was worked into the ground.

Scraping the surface without disturbing it more than necessary greatly increased the development of nitrates as compared with cultivating.

MOISTURE AND TEMPERATURE STUDIES.

In connection with the nitrate studies heretofore reported, moisture determinations were made on each sample (Table 5) and the temperature for each treatment recorded by means of soil thermographs (Table 6). Seasonal rainfall is shown in Table 7.

The plats to which straw had been applied contained slightly more moisture than the untreated plats, the difference being greatest where the straw was applied as a top dressing. The difference in all cases was not great.

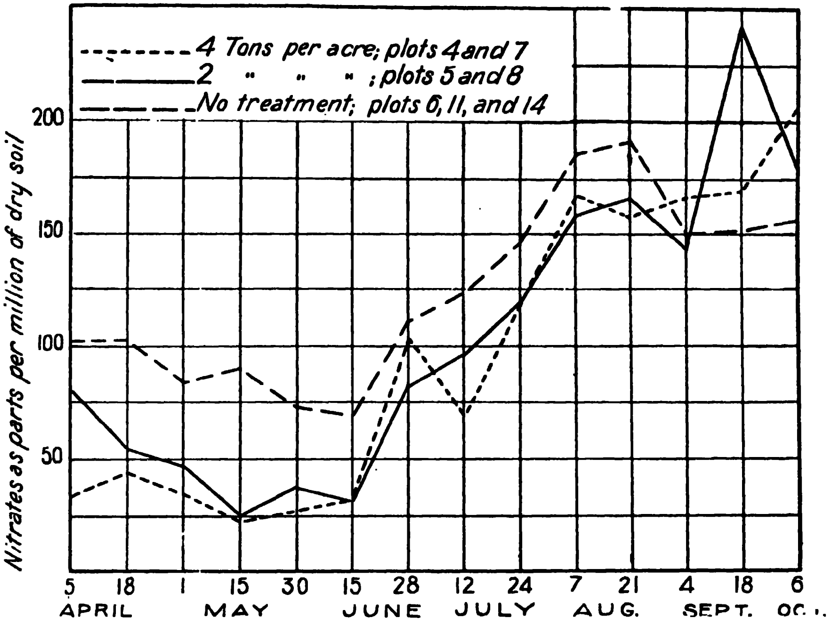


FIG. 13. Graph showing effect on nitrates in the surface soil of different applications of straw worked into the ground (Weeds removed during the following season by scraping).

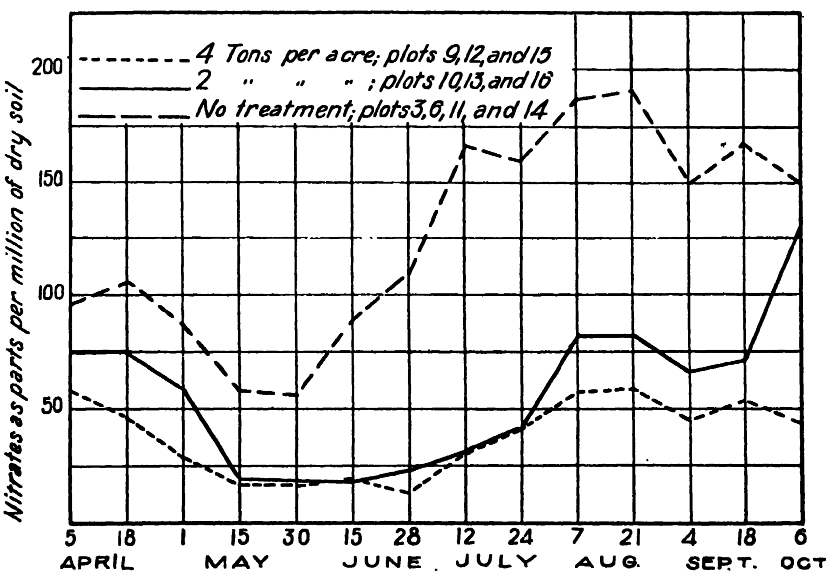


FIG. 14. Graph showing effect on nitrates in the surface soil of straw applied as a top dressing.

TABLE 5.—*Effect of application of straw on the moisture content of the surface foot of the soil.*

Plat No.	Treatment.	Moisture content, percent.							
		Apr. 5, 1916.	Apr. 18, 1916.	May 1, 1916.	May 15, 1916.	May 30, 1916.	June 15, 1916.	June 28, 1916.	July 17, 1916.
1	4 tons straw[a]	22.0	23.2	27.0	26.7	24.5	26.5	22.7	22.7
2	2 tons straw[a]	22.0	23.0	26.5	26.2	19.7	25.0	22.0	22.0
3	None[a]	21.0	23.0	25.0	25.5	21.0	24.2	21.2	21.2
4 and 7	4 tons straw[b]	19.3	21.2	25.2	25.7	19.3	23.5	22.0	18.7
5 and 8	2 tons straw[b]	20.2	20.3	24.0	25.7	17.0	24.2	21.6	18.8
6, 11 and 14	None[b]	21.0	20.6	24.4	25.0	22.0	22.7	20.0	17.5
9, 12 and 15	4 tons straw[c]	24.4	24.6	26.1	25.8	26.4	22.7	23.0	19.5
10, 13 and 16	2 tons straw[c]	22.7	23.2	25.6	25.0	25.5	22.5	19.8	15.9
6, 11 and 14	None[c]	21.0	20.6	24.4	25.0	22.0	22.7	20.0	17.5

Plat No.	Treatment.	Moisture content, percent.						
		July 24, 1916.	Aug. 7, 1916.	Aug. 21, 1916.	Sept. 4, 1916.	Sept. 18, 1916.	Oct. 6, 1916.	Average.
1	4 tons straw[a]	15.7	15.0	17.6	15.4	25.8	20.5	21.8
2	2 tons straw[a]	15.0	16.2	19.8	17.6	26.0	19.8	21.5
3	None[a]	13.0	16.2	17.0	17.7	25.8	19.0	20.7
4 and 7	4 tons straw[b]	14.0	13.5	12.2	14.3	23.4	18.3	19.4
5 and 8	2 tons straw[b]	15.8	13.0	9.2	15.1	22.4	17.9	18.9
6, 11 and 14	None[b]	10.9	13.1	17.4	16.8	22.0	18.4	19.3
9, 12 and 15	4 tons straw[c]	16.0	15.0	17.4	17.4	26.9	20.7	21.8
10, 13 and 16	2 tons straw[c]	12.5	13.3	18.0	15.7	25.5	18.7	20.3
6, 11 and 14	None[c]	10.9	13.1	17.4	16.8	22.0	18.4	19.3

[a] Straw worked in, in the fall; ground cultivated during following season.

[b] Straw worked in, in the fall; weeds removed by scraping during the following season.

[c] Straw applied as a top dressing in the fall; weeds pulled during the following season.

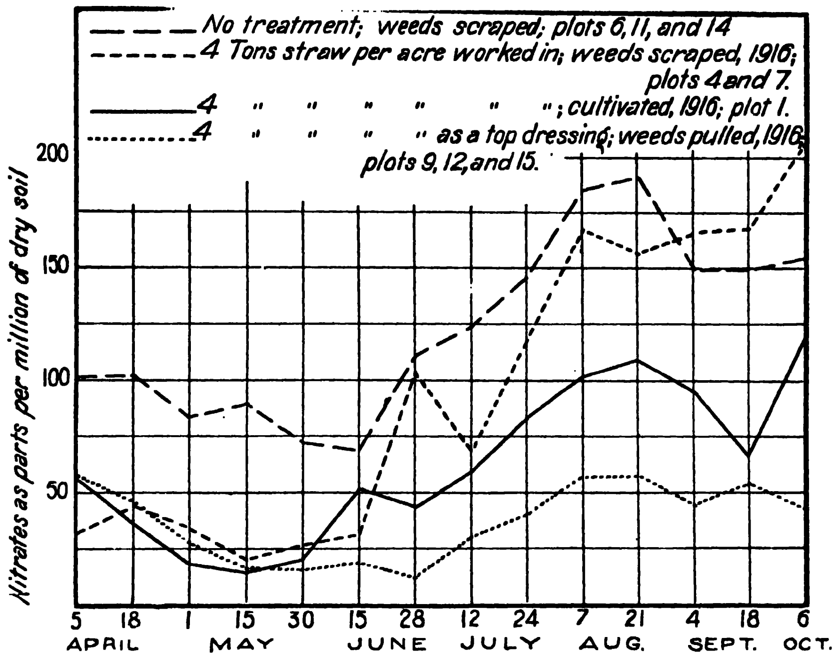


FIG. 15. Graph showing effect on the nitrates in the surface soil of straw applied in various ways.

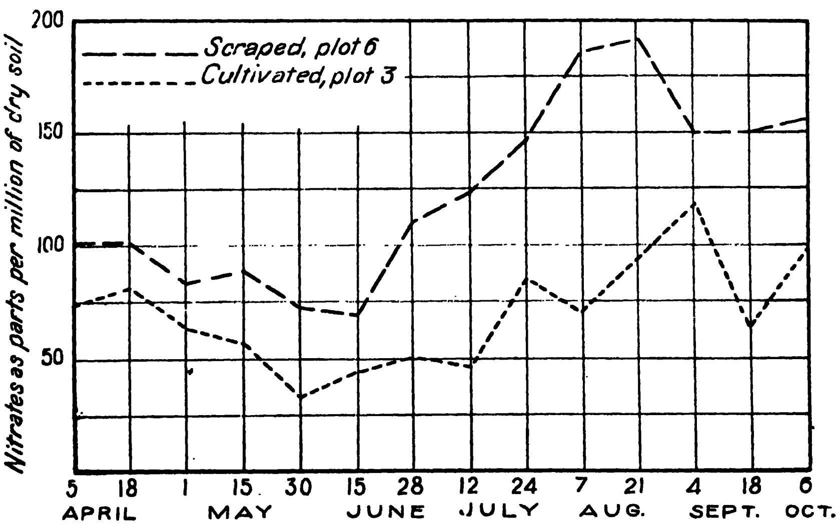


FIG. 16. Graph showing relative effect on the nitrate content of the surface soil of cultivating and removing the weeds by scraping.

Table 6.—*Mean maximum, mean minimum and average weekly temperatures in degrees F.*

MEAN MAXIMUM TEMPERATURES.

Month.	Week.	Treatment. None.	4 tons worked in.	2 tons worked in.	4 tons as a top dressing.	2 tons as a top dressing.
April	1	60.0		61.0	54.0	57.0
	2	63.7		63.0	55.1	56.5
	3	62.0		67.0	59.0	60.1
	4	70.1		70.4	59.3	61.5
May	5	68.0		68.0	59.0	61.7
	6			85.4	69.5	72.0
	7	73.0		72.7	64.0	65.3
	8	87.0		86.4	76.0	77.0
June	9	94.4		93.0	79.5	81.7
	10	87.5		86.5	73.5	75.7
	11	85.0		84.8	75.5	76.1
	12	91.0	90.5	91.0	78.4	81.4
	13	104.5	104.0	104.0	86.4	91.8
July	14	113.0	111.4	109.8	90.3	99.0
	15	111.7	110.7	109.3	92.7	103.0
	16	111.5	110.0	109.1	92.7	97.6
	17	116.0	115.0	115.0	94.7	102.7
August	18	119.8	117.5	118.0	97.1	106.8
	19	115.0	112.0	113.7		100.1
	20	112.0	100.0	110.4	93.3	97.0
	21	114.0	110.0	112.0	97.7	98.4
	22	99.0	93.4	96.4	85.5	85.0
September	23	101.7	99.0	101.0	90.7	89.7
	24	87.5	84.7	87.1	76.5	76.0
	25	92.6	88.8	92.0	79.0	79.2

MEAN MINIMUM TEMPERATURES.

Month.	Week.	None.	4 tons worked in.	2 tons worked in.	4 tons as a top dressing.	2 tons as a top dressing.
April	1	41.0		38.3	41.5	46.5
	2	47.6		45.1	46.1	47.3
	3	45.0		47.5	49.1	47.0
	4	46.7		47.1	46.3	46.3
May	5	47.5		48.8	46.5	48.5
	6			60.8	56.5	57.7
	7	49.1		51.0	52.5	49.8
	8	63.7		63.7	64.1	63.0
June	9	63.5		64.5	64.4	63.7
	10	56.3		57.8	58.5	57.5
	11	62.0		62.1	61.8	61.4
	12	64.8	63.7	65.7	64.4	65.3
	13	71.1	70.7	72.0	69.8	70.3

TABLE 6.—*Mean maximum, mean minimum and average weekly temperatures in degrees F. (Continued).*

MEAN MINIMUM TEMPERATURES.

Month.	Week.	Treatment. None.	4 tons worked in.	2 tons worked in.	4 tons as a top dressing.	2 tons as a top dressing.
July	14	72.3	75.0	75.0	71.8	74.7
	15	76.8	76.4	78.1	74.1	78.8
	16	75.7	74.3	75.0	72.5	75.1
	17	77.1	78.1	78.8	74.4	77.4
August	18	82.4	83.3	83.4	78.7	83.5
	19	79.7	80.3	80.5		81.3
	20	78.3	78.5	79.1	76.3	78.8
	21	71.0	71.8	72.8	70.1	74.1
	22	61.4	63.0	64.8	63.0	65.8
September	23	73.4	71.0	72.5	70.3	72.1
	24	55.4	53.4	56.1	54.4	55.3
	25	54.7	53.2	55.6	53.8	55.0

AVERAGE WEEKLY TEMPERATURES.

Month.	Week.	None.	4 tons worked in.	2 tons worked in.	4 tons as a top dressing.	2 tons as a top dressing.
April	1	50.5		49.6	47.7	51.7
	2	55.6		54.0	50.6	51.9
	3	53.5		57.2	54.0	53.5
	4	58.4		58.7	52.8	53.9
May	5	57.5		58.4	52.7	55.1
	6			73.1	63.0	64.8
	7	61.0		61.8	58.2	57.5
	8	75.3		75.0	70.0	70.0
June	9	78.9		78.7	71.9	72.7
	10	71.9		72.1	66.0	66.6
	11	73.5		73.4	68.6	68.7
	12	77.9	72.1	78.3	71.3	73.3
	13	87.7	87.3	83.0	78.1	81.0
July	14	92.6	83.2	82.8	81.0	86.8
	15	94.2	84.5	83.7	83.1	90.9
	16	93.6	92.1	92.0	82.6	86.3
	17	96.5	96.5	96.9	84.2	90.0
August	18	101.1	100.1	100.7	87.9	95.1
	19	97.3	96.1	97.1		90.7
	20	95.1	93.2	94.7	84.8	87.9
	21	92.5	78.2	80.6	74.2	75.4
	22	80.2	78.2	80.6	74.2	75.4
September	23	87.5	85.0	86.7	80.5	80.9
	24	71.4	69.0	71.6	65.4	65.6
	25	73.6	71.0	73.8	66.4	67.1

The untreated plats and the plats on which the straw was worked into the soil showed very uniform temperatures. Where the straw was applied as top dressing, the temperatures were consistently lower than the untreated plats, the average for the 2-ton application being 3.3° F. less and for the 4-ton application 8.3° F. less than the untreated soil.

TABLE 7.—*Daily rainfall in inches at Manhattan, Kans., April to September, 1916.*

Day.	April.	May.	June.	July.	August.	September.
1						
2						
3		0.07				
4			0.50			
5			.40			
6	0.10		.41			
7	.08					2.38
8						
9						
10			.62			
11		1.29	1.06			3.48
12	.37		2.95			1.19
13		.23				
14	.28	1.95				
15		.18	.44			
16			.05			
17						
18						
19	.25		.99	2.35		
20			.39			
21		1.25				
22						
23		.64				
24	.02					
25			.04			.26
26			.62		0.05	
27		.28				
28						
29	1.04	.53				
30						
31		.23			.13	
Total	2.14	6.65	8.47	2.35	0.18	7.31

SUMMARY.

Applications of straw to soil in the greenhouse caused a marked decrease in the nitrate content. The loss was proportional to the amount of straw added. As decomposition of the straw progressed the nitrates in the soil increased but remained lower in the presence of straw than in the untreated soil. The addition of nitrogen as $(NH_4)_2SO_4$ with the straw caused a more rapid accumulation of nitrates.

Heavy fall applications of straw to wheat growing in the field retarded growth the following spring, delayed the ripening of the grain, and reduced the yield except on soils having a high nitrate content when the straw was applied.

Four tons of straw per acre worked into the surface 6 inches of uncropped soil resulted in a lower nitrate content the following spring, but during the summer the accumulation of nitrates was equal to that in the untreated plats.

Two tons of straw per acre worked into the surface 6 inches did not lower the nitrate content of the soil the following spring.

Four tons of straw applied as a top dressing reduced the nitrate content the following spring and summer. This treatment showed, thruout the summer, the highest moisture content, the lowest temperature, and the lowest nitrate content of any of the treatments.

Two tons of straw applied to the surface did not show an appreciable decrease in nitrates the following spring and the accumulation of nitrates was fairly great by the end of summer.

LITERATURE CITED.

1. BREDEMANN, G. Tests of a bacteria inoculating preparation. *In* Landw. Jahrb., Bd. 43, pp. 669–695. 1913.
2. CHIRIKOV, F. V., and SHMUK, A. A. Experiments on denitrification. *In* Izv. Moskov. Selsk. Khoz. Inst. 19, no. 2, pp. 270–286. 1913. *Abs. in* Internat. Inst. Agr. Mo. Bul. Agr. Intel. and Plant Diseases, v. 4, no. 10, pp. 1528–1529. 1913.
3. CLARK, H. W., and ADAMS, GEO. O. The influence of carbon on nitrification. *In* Jour. Indus. and Engin. Chem., v. 4, p. 272. 1912.
4. COLEMAN, L. C. Untersuchungen über Nitrifikation. *In* Centbl. Bakt., Abt. 2, Bd. 20, p. 401. 1908.
5. CONN, H. W. Agricultural Bacteriology. 103 p. Philadelphia, 1901.
6. ENGBERDING, DIEDRICH. Vergleichende Untersuchungen über die Baktierenzahl im Ackerboden in ihrer Abhängigkeit von äusseren Einflüssen. *In* Centbl. Bakt., Abt. 2, Bd. 23, p. 601. 1909.
7. FRANKFORT, S., and DUSCHECHKIN, A. Course of nitrification under the conditions of field experiments. *In* Russ. Jour. Expt. Landw., v. 8, no. 6, p. 707. *Abs. in* Expt. Sta. Record, v. 20, no. 6, p. 519. 1909.
8. GREAVES, J. E., and CARTER, E. G. Influence of barnyard manure and water upon the bacterial activities of the soil. *In* Jour. Agr. Research, v. 6, no. 23, p. 898. 1916.
9. HILL, H. H. Effect of green manuring on soil nitrates under greenhouse conditions. Va. Agr. Expt. Sta. Tech. Bul. 6. 1913.
10. HILTNER, L., and PETERS, L. The action of straw manure on fertility of soils. *In* Expt. Sta. Record, v. 19, no. 2, p. 119. 1907.
11. JENSEN, C. A. Relation of nitrification to field factors. U. S. Dept. Agr., Bur. Plant Indus. Bul. 273. 1910.

12. KARPINSKY, A., and NIKLEWSKY, B. Über den Einflusz organischer Verbindungen auf den Verlauf der Nitrifikation in unreinen Kulturen. Ext. D. Bul. de l' Acad. d. Sci. de Cracovie 1907.

13. KING, F. H., and WHITSON, A ... tribution of nitrates in cultivated ... 18 p. 1902.

14. LEMMERMAN, O., and ... die msetzung des stickstoffs Verschiedener. *In* Landw. Jahrb., Bd. 38, pp. 101–113. 1909.

15. LÖHNIS, F. Über Nitrifikation und ... in der Ackererde. *In* Centbl. Bakt. Abt. 2, Bd. 12, p. 448. 1912.

16. LYON, T. L., and BIZZELL, J. A. Some relations of certain higher plants to the formation of nitrates in soils. Cornell Univ. Agr. Expt. Sta. Memoir 1. 1913.

17. MCBETH, I. G., and WRIGHT, R. C. Certain factors limiting nitrification *Abs. in* Science, v. 35, no. 897, p. 392. 1912.

18. NIKLEWSKY, B. The influence of the distribution of nitrogenous fertilizers and straw in soil on plant production. *In* Ztschr. Landw. Versuchsw. Osterr., 18, no. 12, pp. 674–690. 1915. *Abs. in* Expt. Sta. Record, v. 35, no. 6, p. 518. 1916.

19. PERCIVAL, JOHN. Agricultural Botany, 765 p. Henry Holt & Co., N. Y. 1900.

20. PFEIFFER, T. The nitrogen economy of cultivated soils. *In* Landw. Inst. Breslau, v. 4, p. 733. *Abs. in* Expt. Sta. Record, v. 21, p. 417. 1909.

21. PITCHARD, P. Effect of different proportions of clay and organic nitrogen on the fixation of atmospheric nitrogen, the conservation of nitrogen, and nitrification. *Abs. in* Expt. Sta. Record, v. 3, p. 636. 1892.

22. POTTER, R. S., and SNYDER, R. S. Determination of amino acids and nitrates in soils. Iowa Agr. Expt. Sta. Research Bul. 24, pp. 327–352. 1915.

23. SNYDER, HARRY. Soils and Fertilizers. 137 p. The Macmillan Co., N. Y. 1909.

24. STEVENS, F. L., and WITHERS, W. A. The inhibition of nitrification of organic matter, compared in soils and in solutions. *In* Centbl. Bakt., Abt. 2, Bd. 27, p. 169. 1910.

25. WARRINGTON, ROBT. Lectures on the Investigations at Rothamsted Experiment Station. Vol. 3, Nitrification, p. 43, Govt. Printing Office, Washington. 1892.

26. WINOGRADSKY, S., and OMELIANSKY, V. Ueber den Einflusz der organischen Substanzen auf die Arbeit der nitrifizierenden Mikrobien. *In* Centbl. Bakt., Abt. 2, Bd. 5, p. 329. 1899.

27. WITHERS, W. A., and FRAPS, G. S. Nitrifying powers of typical North Carolina soils. Rpt. N. C. Agr. Expt. Sta., 1902–1903, pp. 57–63. 1903.

28. WRIGHT, R. C. The influence of certain organic materials upon the transformation of soil nitrogen. *In* Jour. Amer. Soc. Agron., v. 7, no. 5, p. 193. 1915.

TUDY OF HYBR ... ATS AVE

S. Wakabayashi.[2]

The present research was undertaken to collect some facts regarding the inheritance of smut resistance, sterility, panicle shape, color of the flowering glume, dwarfness, and correlations among these characters in the F_2 and F_3 of Red Rustproof (*Avena sterilis*) × Black Tartarian oats (*Avena orientalis*). Smut resistance, sterility, and dwarfness directly affect the production of oats and, therefore, these factors are very important from an economic as well as a scientific viewpoint.

According to the estimate by the Plant Disease Survey of the U. S. Department of Agriculture, the loss of oats due to smut is as shown in Table 1.

Table 1.—*Losses due to oat smuts in Washington in 1917, 1918, and 1919, and in the United States in 1917 and 1918.*

Year.	Washington. Production, bushels.	Washington. Loss due to smuts. Bushels.	Washington. Loss due to smuts. Percent.	United States. Production, bushels.	United States. Loss due to smuts. Bushels.	United States. Loss due to smuts. Percent.
1917.....	11,242,000	348,000	3.3	1,587,286,000	91,648,000	5.26
1918.....	8,370,000	251,000	3.0	1,538,359,000	64,396,000	4.20
1919.....	12,800,000	384,000	3.0			

Some fields in Washington have lost as high as 25 percent of the oat crop on account of smut. By far the greatest loss in the State is due to covered smut, *Ustilago laevis avenae*. If a variety of oats immune to covered smut and as high in production as our best commercial varieties could be produced, it would save 3 percent of the crop, which is worth about $300,000 at present prices. The loss due to sterility and dwarfness has not been measured, but it is safe to assume that these characters diminish to a considerable extent the total production of the country.

[1] Contribution from Department of Farm Crops, Washington Agricultural Experiment Station, Pullman, Wash. Received for publication October 25, 1920.

[2] The writer desires to acknowledge courtesies extended by the Washington Agricultural Experiment Station, and particularly by Prof. E. F. Gaines, under whose direction this work was undertaken.

HISTORICAL.

The writer has been unable to find anything in print on the resistance of oats to covered smut.[3] As to rust resistance, Parker (3, 4)[4] found that the *Avena sterilis* group is [illegible] resistant [illegible] both *Puccinia graminis avenae* and *P.* [illegible] up, but there are some varieties of th[illegible] eptil[illegible] while others are resistant. He favors the multiple factor theory.

Appearance of dwarf plants has [illegible] reported in the literature. Warburton (5) reports the sudden appearance of dwarf plants as a simple Mendelian recessive in a head-row selection of a common oat variety, Victory.

Gaines (1), Nilsson-Ehle (2), Wilson (6), and others have found that the black color of the floral glume in the oat is a simple Mendelian factor in some crosses and composed of multiple factors in others.

The shape of the panicle was found to be very irregular. The side shape bred true, while some intermediate panicles also bred true and others segregated irregularly, indicating multiple factors for this characteristic also.

METHOD AND MATERIAL.

The female parent, Red Rustproof (Wash. No. 768) belongs to *Avena sterilis*. In the varietal test of 1919 it was about 32 inches tall, fine and stiff; panicles small, upright, and pyramidal, floral glumes greasy in appearance and very slightly reddish tinted; outer glumes not so white as those of *A. sativa;* bristles at the bottom of the first floret abundant and very prominent; awns twisted once, white; stooling rather pronounced and with many green tillers which did not mature before harvest.

Black Tartarian (Wash. No. 762) belongs to *Avena orientalis.* It had straw in 1919 about 42 inches in height, very large but rather soft. Stooling was less marked than in the case of *Avena sterilis.* Panicles of side or horsemane type, long, and bearing more kernels than those of *Avena sterilis;* floral glumes dark brownish or black; awns dark and twisted twice; bristles few and small.

Comparison of the two parents in tabular form is shown in Table 2.

[3] Since this paper was written, Reed has reported that *Avena sterilis* forms usually are resistant to covered smut, while *A. sativa* forms usually are susceptible (Mo. Agr. Expt. Sta. Research Bul. 37, 1920).

[4] Reference by number is to "Literature cited," p. 266.

TABLE 2.—*Comparison of Red Rustproof and Black Tartarian oats in certain characters.*

Characteristics.	Red Rustproof.	Black Tartarian.
Average height, inches	32	42
[illegible] number of culms [illegible] [illegible]een ones)	[illegible]	[illegible]
[illegible]rage number of ke[illegible]	[illegible]	[illegible]
Susceptibility to smut	Immune	Susceptible (ave. 34 perc[illegible])
Percent of sterile flowers	25	14
Shape of the panicle	Pyramidal	One-sided
Average length of panicle, inches	5	11

These parents were crossed reciprocally in 1916, and F_1 plants from three seeds were grown in 1917. The seed from one was sown in 1918, and 112 F_2 plants were produced. One panicle from each of these 112 Red Rustproof × Black Tartarian plants was saved, and in 1919 the kernels from these were inoculated with covered smut of oats and sown in separate rows to test their smut resistance. Seed of both parents was similarly treated, as was also the seed from the sib and the reciprocal plant grown in 1917. One of these produced 49 and the other 26 plants in 1919, the small numbers perhaps being due in part to the fact that the seeds were inoculated with smut. The F_3 rows contained an average of only 12.2 plants per row.

The kernels of a representative panicle from each of the F_2 plants were classified according to the color of the floral glumes into *BB* (black), *Bb* (brown), and *bb* (white), and the numbers of sterile and fertile flowers were also recorded.

The F plants were separated according to the color of the floral glumes and panicle type, i.e., they were first divided into black and white, then each class was further divided into pyramidal, intermediate, and side type, and the number of each was recorded. Since it was somewhat difficult to separate *Bb* from *BB*, the only color separation was black and white. One representative panicle from each plant was then collected and thrashed separately. The percentage of sterility was calculated from actual counts of sterile and fertile flowers. Ten typical panicles of each parent were thrashed and counted for comparison. For calculating the smut loss, the smutted plants were first separated into those all smutted and those partly smutted. Then the partly smutted group of each row was separated into smutted and nonsmutted panicles. Those panicles which were half or less smutted were counted as non-smutted while those with more than half smut were recorded smutted. The product of the percentage of the partly

smutted plants and the pe[illegible] [illegible]utted plants was added to that of the per[illegible] [illegible]d, to get the percentage of loss due to smut for the row.

RESULTS.

SMUT RESISTANCE.

Red Rustproof has never shown a single indication of smutting, altho sown repeatedly under conditions favoring maximum smut infection. Black Tartarian has produced from 25 to 40 percent of smut under the same conditions. The F_1 and F_2 have never produced a trace of smut. In the F_3 smut was found in 12 rows, while 95 were immune. The amount of smut produced in the 12 rows was 15, 12, 9, 8, 4, 4, 4, 3, 3, 2, 2, and 0.1 percent respectively. The most susceptible F_3 row produced less than half as much smut as the susceptible parent. As to the cause of immunity of F_2 and pronounced resistance in F_3, the results indicate the existence of multiple factors. Keeping in mind the fact that the susceptible parent showed smut on less than half the plants, the F_3 is nearly what is to be expected if the immunity of Red Rustproof is caused by three independent dominant factors any one of which would prevent the appearance of covered smut.

The fact that resistance is dominant is unusual, inasmuch as it has been reported as recessive in wheat yellow rust by Biffen and by Nilsson-Ehle and in stinking smut of wheat by Gaines.

STERILITY.

The record shows that Red Rustproof is higher in sterility than Black Tartarian. Their crosses are comparatively high in sterility, tho decreasingly so generation after generation because of sterile strains eliminating themselves. When a representative panicle from each individual was counted for sterility it was noticed that some were 100 percent sterile, while a few were less than 5 percent sterile. Table 3 shows sterility in the parents, F_1, F_2, and F_3 rows.

TABLE 3.—*Comparative sterility of Red Rustproof and Black Tartarian oats and the first three generations of hybrids between them.*

Variety.	Number of fertile flowers.	Number of sterile flowers.	Sterility, percent.
Red Rustproof	454	112	25
Black Tartarian	1,452	246	14
Red Rustproof × Black Tartarian, F_1	122	197	62
Red Rustproof × Black Tartarian, F_2	2,802	3,663	57
Red Rustproof × Black Tartarian, F_3	39,721	23,935	38
Black Tartarian × Red Rustproof F_1	68	167	71
Black Tartarian × Red Rustproof F_2	1,158	620	35

Table 3 shows de·
averaged, but the increased fertility of some of the F_3 rows offers a suggestion of multiple factors and i· ·f economi.

COLOR OF THE FLORAL GLUMES.

Seeds from F_2 plants of 1918 were separated into three classes according to the color, 24 *BB* (black) 60 *Bb* (intermediate black), and 26 *bb* (white). This artificial classification of the color of the floral glumes was shown to be inaccurate by sowing these seeds and observing the segregation. The 24 classified as *BB* proved to be 17 *BB* and 6 *Bb*, 1 not producing plants. The 60 classified as *Bb* proved to be 22 *BB* and 32 *Bb*, 5 not producing any plants and 1 producing only 2 white plants. Those classified as *bb* all bred true to whiteness.

The F_3 is far from the ratio 1:2:1. However, if the two colored classes are combined, the ratio is 72 percent with color and 28 percent white, which approaches the 3: 1 ratio. This shows the difficulty of distinguishing *BB* from *Bb*. The F_2 sib and the reciprocal in 1919 produced an average of 24 percent of plants with white floral glumes. This makes it certain that color in this cross reacts as a unit factor.

SHAPE OF PANICLE.

Much time was spent in an attempt to classify the F_2 and F_3 panicle types segregating in 1919, but owing to the rapidity with which the material ripened and the changes produced by different stages of maturity the classification as presented is unsatisfactory and more or less unreliable. It is sufficiently accurate, however, to show that the inheritance of the side or horsemane type of panicle is recessive but produced by multiple factors. The F_2 of Black Tartarian × Red Rustproof produced 6 plants with side panicle and 43 that varied thru all intermediate stages to the pyramidal type. The reciprocal in which Red Rustproof was used as the pistillate parent seemed to show a greater tendency toward the side type in the F_2. Eight plants were so classified in a row that produced only 18 others that were intermediate or pyramidal. The F_3 produced only 5 rows out of 107 that were 100 percent side type. Twenty-five rows were classified as pure pyramidal, but very few showed the wide spreading habit of Red Rustproof. The material was overripe before the classification was completed. Of the 1,318 plants, 53 percent were classified as pyramidal, 27 percent were put in the intermediate class, and 20 percent seemed to be as near side type as the overripe Black Tartarian parent.

DWARFNESS.

In most cases those plants which were below 24 inches in height were counted as dwarf. However, some plants were counted as normal because of their vigor even tho they were a little below normal in height.

The dwarf plants varied greatly in size and vigor. Some died early as the dry season came on, or remained in green tufts, or were scarcely able to produce seeds, while others produced almost normal seeds. In the F_3, 143 plants were classified as dwarf out of 1,327. From one to many dwarfs appeared in 58 of the 107 rows. The others produced only normal plants. The two F_2 rows representing reciprocal crosses produced 75 plants, 7 of which were dwarfed.

The appearance of dwarf plants among the progenies of a cross is not rare, tho the causes never have been studied to the writer's knowledge. Dwarfness and sterility may be due to the same or related causes, since the dwarf plants have weak, soft, slender culms with panicles high in percentage of sterile flowers.

From the numbers of dwarf plants produced by the F_2 families (9.3 percent), it appears to be safe to assume that dwarfness is not produced by a simple factor. The fact that 51 percent of the F_2 plants produced some dwarf plants in F_3 is a nearer approach to simple Mendelism. High mortality in dwarf plants may possibly have operated to change a 3:1 ratio to the figures actually obtained. In only two rows were all the plants dwarf. The dwarf F_3 parent plants were not recorded, but no doubt more than two were planted. The others evidently were not homozygous for the dwarf character or else the plants all died, as 5 rows were blank. If dwarfness were a simple recessive factor, 75 percent of all rows would give rise to dwarfs instead of 51 percent of the F_3 rows. However, it must be remembered that the actual figures are the outcome after the weakness and sterility of seeds of a wide cross played their parts of elimination.

CORRELATION AMONG CHARACTERS CONSIDERED.

It was noted that those 18 plants that produced smut were mostly dwarfed and had the side type of panicle, as is shown in Table 4.

There seems to be some relation between the production of smut and dwarfness. It is difficult to say whether weak plants are apt to be attacked by smut or the presence of the smut fungus is a cause of dwarfness. Tho five smutted plants were not classified as dwarfs, yet they were below the normal height because most of the healthy plants ranged from 28 to 33 inches.

TABLE 4.—*Classification of smutted oat plants according to color of floral glume, shape of panicle, and height.*

Black side.*		Black pyramidal.		White side.		White intermediate.		White pyramidal.	
No. plants.	Height, inches.	No. plants.	Height, inches.	No. plants.	Height, inches.	No. plants.	Height, inches.	No. plants.	Height, inches.
1	6	1	28	1	16	3	20	1	18
1	16			2	20			1	27
1	18			2	22				
1	24			1	26				
1	27			1	27				

The table seems to indicate also a relation between smut susceptibility and white floral glume and also between smut susceptibility and side character of the panicle. However, dwarf plants are weak and usually retarded and the panicles show more or less close resemblance to the side character. The color of the floral glume also is not well developed, so that the white glumes and side panicles may have been wrongly classified, but this is hardly probable.

Dwarf plants were difficult to separate according to the color and panicle shape because of their imperfect maturation. The number and height of the dwarf plants were as follows:

Height, inches............	9	12	13	14	15	16	17	18	19	20	21	22	23
No. plants................	1	6	5	5	7	1	8	20	17	12	23	26	12

In the reciprocal F_2, out of 49 plants there were six dwarfed, one measuring 16 inches and the rest 23 inches. In the F_2 sibs, out of 26 plants, three were dwarfed, two measuring 18 inches and one 23 inches. It also should be mentioned that the parent Red Rustproof sown for comparison had, out of 48 plants, four plants dwarfish, two measuring 20 inches, one 18 inches, and one 16 inches. These, however, in their vigor and fecundity were more like normal.

An analysis of the data shows that sterility is not in any way related to the color of the floral glume or the shape of the panicle, as it is more or less evenly distributed among all the characters considered. There is a definite correlation between dwarfness and sterility, but since the dwarf and normal plants were not kept separate in the laboratory where the sterility counts were made, it can not be put in tabular form.

SUMMARY.

The F_1, F_2, and F_3 generations of Red Rustproof (*Avena sterilis*) × Black Tartarian oats (*Avena orientalis*) were studied as to the re-

sistance to smut, sterility, color of the floral glume, shape of the panicle, dwarfness of culm, and correlations among these characters.

Resistance to smut is completely dominant and is caused by multiple factors.

Sterility due to a wide cross is comparatively high in the F_1, but decreases in succeeding generations.

The black color of the floral glume of Black Tartarian is a simple Mendelian dominant character.

The shape of the panicle is probably of multiple factors, if Mendelian.

The production of dwarf plants was interfered with by sterility and it is difficult to state whether it is a simple Mendelian character.

There seems to be some correlation between dwarfness and sterility and between smut susceptibility and dwarfness. There may also be correlation between smut susceptibility and white color of the floral glume and between susceptibility and the side character of the panicle.

Sterility is not correlated with the color of the floral glume or the shape of the panicle.

LITERATURE CITED.

1. GAINES, E. F. Inheritance in wheat, barley and oat hybrids. Wash. Agr. Expt. Sta. Bul. 135. 1917.
2. NILSSON-EHLE, H. Kreuzungsuntersuchungen an Hafer und Weizen. *In* Lunds Universitets Arsskrift., 7: 1–82. 1911.
3. PARKER, JOHN H. Greenhouse experiments on the rust resistance of oat varieties. U. S. Dept. Agr. Bul. 629. 1918.
4. ——. A preliminary study of the inheritance of rust resistance in oats. *In* Jour. Amer. Soc. Agron., 12: 23–38. 1920.
5. WARBURTON, C. W. The occurrence of dwarfness in oats. *In* Jour. Amer. Soc. Agron., 11: 72–76. 1919.
6. WILSON, JOHN H. The hybridization of cereals. *In* Jour. Agr. Sci., 2: 68–88. 1907.

A STUDY OF THE LITERATURE CONCERNING POISONING OF CATTLE BY THE PRUSSIC ACID IN SORGHUM, SUDAN GRASS, AND JOHNSON GRASS.[1]

H. N. VINALL.[2]

In countries where sorghum is important it has been known for many years that this crop frequently causes the death of cattle when they are allowed to eat it in the green state. Pease (13)[3] states that in India the year 1877 was marked by the death of great numbers of cattle due to eating sorghum. The season was especially dry and the crop was "semi-parched for want of rain." Sorghum poisoning was frequent also in 1887 and 1895, which were years of drouth. The natives believed that the sorghum plant became poisonous in dry years when attacked by a small insect which they called "bhaunri." The idea was that the cattle were poisoned by eating this insect. Other theories advanced included the belief that the sorghum leaves collected in the paunch and, by giving off gases, caused death by asphyxiation similar to hoven or bloating.

Pease, in studying the matter in 1895, decided that the death of cattle was due to the consumption of nitrate of potash. He found in the stems of some withered sorghum plants as much as 25 percent of this salt, it being particularly abundant at the nodes. The symptoms of poisoning from nitrate of potash are somewhat similar to the symptoms of prussic acid poisoning. This theory of Pease was disproved later, or at least it was found that it was not the cause of death in most cases of sorghum poisoning.

In the United States the fact that cattle were poisoned by eating green sorghum was recognized by Hiltner (10) of the Nebraska station in 1900. This investigator made a chemical study of sorghum plants taken from a field which had caused the death of cattle, but failed to find the prussic acid, which no doubt was present. He found no substance in the plants which could have caused the death of the cattle and concludes as follows:

[1] Contribution from the Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication November 30, 1920.

[2] Agronomist, Office of Forage-Crop Investigations, Bureau of Plant Industry.

[3] Reference by number is to "Literature cited," p. 279.

Negative results of an analysis are usually not satisfactory but in this case they are at least quite conclusive. In view of the analyses and of the collateral evidence given, it seems certain that the toxic effect of this plant which manifests itself at times is not due to a chemical poison inherent in the plant and is not peculiar to the second growth alone.

It was not until 1902 that the presence of HCN in sorghum plants was discovered. This was first reported by Dunstan and Henry (7), altho Slade, then assistant chemist at the Nebraska experiment station, suggested the probability of such a poison in sorghum in 1901 (17) and actually isolated prussic acid from a sample of fresh sorghum about August 1, 1902 (18). His report of this discovery was sent to the Journal of the American Chemical Society for publication on October 3, 1902. Avery (14, p. 10) asserts that Slade did not know until October 10 of the results obtained by the two English investigators. Dunstan and Henry's paper on this subject was received by the Royal Society of London April 24, read before that Society May 15, and published in the Chemical News of London in the issue of June 27, 1902.

Avery (14) continued the work of Slade and published in 1903 a rather complete summary of the results obtained at the Nebraska experiment station. The work of the three investigators, Peters, Slade, and Avery, left little room to doubt that prussic acid was the direct cause of sorghum poisoning.

That trouble from this source has been common in nearly every country where sorghum is grown to any extent is indicated by reports on sorghum poisoning from Australia, Java, India, Africa, Italy, and the West Indies. It is known that this poisonous principle, prussic acid, exists in other plants belonging to the sorghum family. Crawford (5) found it in Johnson grass in 1906, and since that time other investigators, including Schroeder and Dammann (16), have reported hydrocyanic acid in this grass.

No similar work had been done with Sudan grass until 1915, when Francis (8) of the Oklahoma Agricultural Experiment Station made determinations of the hydrocyanic acid in this grass. In 1919, Menaul and Dowell (12), also of the Oklahoma station, reported a study of cyanogenesis in Sudan grass.

THE FORM IN WHICH PRUSSIC ACID OCCURS IN SORGHUM.

Avery, in the publication before mentioned, declares that prussic acid is not present in sorghums as such, but under certain conditions is liberated from a glucoside by an enzyme in the plant. Glucosides of this sort, he states, are harmless and become dangerous only when

they are hydrolyzed and liberate prussic acid (14, p. 14). This cyanogenetic glucoside in sorghum is called dhurrin and is said by Dunstan and Henry (7) to have the empirical formula $C_{14}H_{17}O_7N$, and "on hydrolysis with hot dilute hydrochloric acid or the enzyme emulsin, yielded one molecule each of prussic acid, parahydroxy-benzaldehyde and dextrose."

The theory of Dunstan and Henry was that sorghum poisoning is caused by the dhurrin and emulsin coming together in the early processes of digestion when the enzyme by the addition of water to the glucoside breaks the latter down and liberates the poisonous prussic acid. Working independently and without knowledge of the findings of Dunstan and Henry in England, Slade and Avery (14, 17) arrived at practically the same conclusions.

Dowell (6) agrees with the Nebraska and British investigators that the acid exists in sorghum only in the form of a glucoside. Willaman (19) of the Minnesota station, however, claims that hydrocyanic acid is found in sorghum in both a glucosidic and a non-glucosidic form. He has support for this theory in the work of the Italians, Ravenna and Babini (15). These two investigators claimed to have found free prussic acid in sorghum leaves as well as in the leaves of cherry-laurel, peach, and flax. In their conclusions, however, they qualify their results somewhat by indicating how easy it would be for a small quantity of free HCN to be produced by autolysis during the progress of the experiment. The form in which HCN occurs in sorghum plants remains, therefore, a matter of dispute among chemists. The known facts regarding the comparative harmlessness of cured sorghum and the fact that the introduction of glucose into an animal's stomach renders the poison relatively innocuous seem to lend support to the glucoside theory.

QUANTITY OF SORGHUM AND OF SUDAN GRASS NECESSARY TO PROVIDE A FATAL DOSE OF HCN.

Avery found that 0.4 gram of the combined prussic acid was sufficient to make an animal very sick. It is probable, therefore, that 0.5 to 0.6 gram or 0.02 ounce would be fatal to a mature animal in most cases. Table 1 indicates the quantity of sorghum or Sudan grass necessary for an animal to eat in order to take into its stomach this amount of prussic acid. The cases cited in the table are percentages obtained by actual analysis of samples as reported in different publications.

TABLE 1.—*Quantity of fresh Sudan grass or sorghum required to provide a sufficient amount of prussic acid to be fatal to cattle.*

Crop.	Condition of crop.	Prussic acid.	Authority.	Material necessary to provide fatal dose.
		Percent.		*Pounds.*
Sudan grass..	Cut June 16, pls. 15 ins. tall	0.0105	Menaul and Dowell (12)	11.9
Do.....	Cut June 23 from same field	0.0053	do	23.6
Do.....	Cut June 30 from same field	0.0069	do	18.1
Do.....	Cut June 30 from same field (leaves only)	0.0155	do	8.1
Do.....	Cut July 14 from same field	0.0052	do	24.0
Do.....	Cut July 31 from same field (second growth)	0.0059	do	21.2
Do.....	Second growth, 15 ins. tall	0.0042	Francis (8)	29.8
Do.....	Second growth, 17 ins. tall	0.0021	do	59.6
Do.....	Second growth, 30 ins. tall	0.0042	do	29.8
Average.....		**0.0066**		**18.9**
Sorghum....	Normal growth 30 ins. (Exp. 4a)	0.0222	Dowell (6)	5.6
Do.....	Normal growth 30 ins. (Exp. 4b)	0.0130	do	9.6
Do.....	Second growth 30 ins. (Exp. 1a)	0.0221	do	5.7
Do.....	Second growth 30 ins. (Exp. 1b)	0.0228	do	5.5
Kafir.......	Normal plant, 40 ins. tall	0.0018	Francis (8)	69.4
Average.....		**0.0164**		**7.6**

Only analyses of sorghums made in Oklahoma by the same men who made the Sudan grass analyses are presented in Table 1, because the methods of chemists in determining the amount of prussic acid differ so widely that it is believed their results are not comparable. Care was used also in selecting from the many analyses of sorghum only those of plants in practically the same condition of growth and vigor as were the Sudan grass samples. With these precautions, it is believed that the comparison between Sudan grass and sorghum is fairly accurate. The average percentage of prussic acid in sorghum is seen to be about two and one half times that in Sudan grass. The average amount of fresh material an animal would have to eat in order to ingest the 0.02 ounce of prussic acid, considered as the amount likely to prove fatal, is 18.9 pounds of Sudan grass and only 7.6 pounds of sorghum.

The proportion of acid in the leaves is nearly always greater than it is in the stems, however, and since the animal is likely to eat mostly leaves when turned into a field, 8 pounds of Sudan grass having the percentage of prussic acid shown by sample 4 in the table would be sufficient to kill an animal, if the liberation of the acid from the glucoside was complete. Fortunately for stockmen, the conditions

in the animal's stomach are not likely to cause complete hydrolysis of the dhurrin contained by the plant, otherwise fatalities among live stock pastured on Sudan grass would be much more numerous than they are.

EFFECT OF CURING SORGHUM OR SUDAN GRASS ON HCN CONTENT.

The very general belief among farmers that sorghum and Sudan grass cured as fodder or hay are usually safe to feed stock is confirmed by the investigations of Avery. He found that it was possible for an animal to consume 1.2 grams of combined prussic acid, when fed well-cured sorghum, without exhibiting any signs of poisoning. One third of this quantity taken into the stomach in fresh uncured sorghum would have been highly dangerous. Avery attributes this apparent harmlessness of the cured sorghum to the inactivity of the enzyme in dried plants. If the enzyme remains inactive, no free prussic acid is formed and the combined prussic acid in the form of the glucoside, dhurrin, does not cause trouble.

Dowell has a different theory regarding the effect of curing sorghums. He states (6, p. 179):

> A comparison of the percentage of hydrocyanic acid found in experiments 1a and 1b with those in 2a and 2b shows that approximately three-fourths of the acid is set free in the process of drying.

He also claims that where the material is dried out slowly more of the acid is volatilized than where the drying is accomplished quickly. His experiment 3a covering this point supports his conclusion thoroly, but the duplicate (experiment 3b) in which the sorghum was also dried quickly had remaining almost exactly the same amount of prussic acid as was found in experiment 2b where the material was dried slowly. If this theory of Dowell's is proved by later experiments it will have a practical application in determining the most desirable methods of curing sorghum and Sudan grass.

EFFECT OF INJURY, ESPECIALLY BY DROUTH AND FROST, ON THE HCN CONTENT.

Another belief of stockmen verified by experiments is that sorghum or Sudan grass injured by drouth or other adverse climatic conditions contains a larger quantity of prussic acid than where the crop has made a normal vigorous growth. In Table 2 a number of comparable analyses are presented showing the difference in prussic acid content of vigorous, healthy sorghum and that stunted by drouth or other adverse climatic conditions.

TABLE 2.—*Percentage of prussic acid in healthy, vigorous sorghum and in that stunted by drouth or injured by frost.*

Crop.	Authority.	Cause of injury.	Percentage prussic acid.	
			Normal plants.	Injured plants.
Sorghum....	Peters, Slade, and Avery (14, p. 13)[a]	drouth	0.0074	0.0112
Do.....	Peters, Slade, and Avery (14, p. 13)[a]	do	.0076	.0274
Do.....	Peters, Slade, and Avery (14, p. 13)[a]	frost	.0133	.0082
Kafir.......	Francis (8, p. 3)	do	.0018	.0037
Sorghum....	Dowell (6, p. 178)	drouth	.0222	.0514
Do.....	Dowell (6, p. 178)	do	.0130	.0450
Do.....	Willaman (20, p. 44)[b]	frost	.0000	.0017
Do.....	Willaman (20, p. 44)[b]	do	.0055	.0072
Average.....			**.0089**	**.0195**

[a] In order to make the results of the analyses of the drouth injured plants comparable with those of the normal plants in which the percentage of HCN is given on the basis of fresh material the wilted plants from Cambridge, Nebr., are presumed to have lost 20 percent of their weight as evaporated moisture and the dried plants from Brighton, Colo., 70 percent of their weight. This reduces the expressed percentage of HCN very decidedly but it is believed that the percentages are thus made comparable.

[b] The percentages as given by Willaman are in the first instance for non-glucosidic, and in the second for glucosidic prussic acid.

From a study of Table 2 it will be seen that in only one case is the observed percentage of HCN higher in normal plants than it is in plants injured by drouth or frost. The average for the series of 8 analyses indicates that we can expect on an average over twice as much prussic acid in injured plants as in normal sorghum plants.

In accepting the above conclusion, however, it is necessary to distinguish between plants stunted by an acute spell of drouth or a frost, when they would otherwise have been growing vigorously, and those stunted by a lack of plant food in the soil. It has been found by a number of investigators (1, 3, 11, 16, and 21) that sorghum plants grown on a poor soil have less prussic acid in them than the plants grown on a rich soil, especially if the poor soil is low in nitrates. The addition of a nitrate fertilizer to a poor soil on which the sorghum was being grown invariably increased the HCN content of the plants. This fact, however, does not disprove the contention of Avery that sorghum injured by drouth usually had a higher HCN content than sorghum of normal growth, nor does it set the findings of Avery at variance with those of Alway and Trumbull as suggested by Willaman and West (21, p. 181). A close analysis of the publica-

tions of the Nebraska investigators shows that their results are not necessarily conflicting on this point, altho their statements apparently give this impression. The crux of the matter seems to be that the HCN content of sorghum plants is increased by injury due to drouth, but is actually decreased by stunting of the plant thru lack of nourishment. Evidently an injury of any kind which results in checking the growth of a sorghum plant results in an increase of HCN.

The belief is common in Australia that sorghum plants attacked by insects are more poisonous than normal plants. Balfour (2) of the Gordon Memorial College, Khartoum, Egypt, analyzed two durra plants of approximately the same age. The plant affected with aphids contained 0.035 percent, and the normal or aphid-free plant only 0.014 percent of HCN. This, of course, is only one analysis and can not be accepted as conclusive.

EFFECT OF PLANT MATURITY ON THE HCN CONTENT.

Regarding the effect of maturity or age on the HCN content of sorghum plants, there is almost complete agreement among chemists as well as farmers. The percentage of prussic acid in sorghum plants decreases steadily from the time the plant begins growth until it ripens its seed, if the growth has been normal. In some cases where the growth has been interrupted by adverse climatic conditions there is noted an actual increase in the HCN content, but except for such abnormalities, sorghum or Sudan grass after it has headed out and set seed is usually safe to feed to cattle or horses.

The most extensive and conclusive series of analyses bearing on this question are those of Willaman and West (21, 22) of the Minnesota experiment station. These findings are supported by those of other investigators, but only a part of the results are given in Table 3, because they seem sufficient to prove the point.

The sorghums in the first four series of analyses were grown in Minnesota, the Sudan grass in Oklahoma, and the two sorghums and the Johnson grass in the last three series were grown in Uraguay, South America. The results of all these analyses are consistent, however, in showing a practically uniform decrease in HCN content from the plant's beginning to its maturity. The confirmatory nature of all these analyses made by different investigators in widely separated regions leaves little to be desired in the way of proof regarding the comparative harmlessness of sorghum, Sudan grass, and Johnson grass when the plants have reached that stage of maturity in which seed is being formed.

TABLE 3.—*The effect of maturity on the hydrocyanic-acid content of sorghum and Sudan grass.*

Crop.	Age of plants.	Height of plants.	Stage of maturity.	HCN in the whole plant.[a]	Reference No.
	Days.	*Inches.*		*Percent.*	
Sorghum.......	31	18		0.083	21, p. 181
	38	28		.032	
	52	39		0	
	55	42		.007	
	62	61		.002	
Do........	32	26		.064	do
	39	34		.043	
	45	40		.024	
	62	56		.007	
Do........	32	26		.068	do
	39	38		.045	
	52	42		.021	
	62	59		0	
Do........	33	14		.114	22, p. 263
	42	18		.028	
	52	28		.019	
	62	38		.009	
	73	56		.002	
	83	67		.001	
	93	78		Trace	
Sudan grass.....	22	15	Very young	.0579	12, p. 448
	29	—		.0274	
	36	—		.0291	
	43	—		.0094	
Sweet sorghum..	44	8	Very young	.0293	16
	62	25	Before heading	.0211	
	99	42	Beginning to bloom	.0057	
	119	46	Blooming	.0048	
	135	50	Beginning to seed	.0013	
Grain sorghum..	44	16	Very young	.0192	16
	62	25	Before heading	.0176	
	103	42	Beginning to bloom	.0065	
	120	54	Full bloom	.0053	
	135	58	Beginning to seed	.0025	
Johnson grass...	44	8	Before heading	.0137	16
	74	13	Beginning to bloom	.0036	
	94	25	Full bloom	.0028	
	109	25	Beginning to seed	.0040	
	130	25	Seed ripe	.0028	

[a] The percentages of HCN are all given on a dry-matter basis.

RELATION OF CLIMATE TO THE HYDROCYANIC-ACID CONTENT OF PLANTS.

It is a matter of general knowledge among those who work with forage crops that cases of prussic acid poisoning are much less

common in the Gulf States than in States farther north. Very few complaints regarding sorghum poisoning are received from points in the United States south of 35°, North latitude. This parallel marks the northern boundaries of South Carolina, Georgia, Alabama, and Mississippi, divides Arkansas practically in half, and passes thru or near the towns of Chickasha, Okla., Clarendon, Tex., Santa Rosa, N. Mex., Winslow, Ariz., and Mojave, Calif.

The evidence concerning the comparative harmlessness of sorghum, Sudan grass, and Johnson grass in the region south of parallel 35° is not quite so clear for the Southwestern States as it is for the region east of central Texas. This fact can perhaps be accounted for by the high altitudes and intense drouths of New Mexico, Arizona and southern California. Just why the sorghum plant and its related species should be so much more dangerous in Kansas, Nebraska, and eastern Colorado than in eastern Texas, Louisiana, Mississippi, Alabama, Georgia, South Carolina, and Florida has never been satisfactorily explained. The three crops are widely grown in both regions and acute dry periods are likewise common to both.

Willaman and West (22) of the Minnesota station are the only investigators who have made a serious attempt to study the effect of climate on the hydrocyanic-acid content of sorghums, and unfortunately all their samples were obtained from points considerably north of the 35th parallel. They determined the HCN content of sorghum plants grown in Minnesota, South Dakota, Kansas and Utah. The spread was east and west rather than north and south. Their conclusion from this work was that varietal differences were a larger factor in determining the amount of HCN in a sorghum plant than climate. It is impossible to accept this valuation of the climatic effect, however, until it is verified by comparing sorghum grow in Florida, Georgia, or some other Gulf State with plants grown in Minnesota, the Dakotas, Nebraska, or Kansas.

An interesting side light on the problem is furnished by the analyses of some sorghums grown in Florida (4). Amber, one of the varieties used in the Minnesota experiments, when grown in Florida showed absolutely no prussic acid. In Minnesota this variety at the same height had 0.28 percent of prussic acid on a dry matter basis On the basis of fresh material, as used in Florida, Amber sorgo in Minnesota would have 0.0066 percent of prussic acid, a larger percentage than any of the varieties included in the Florida analyses.

There are at least three possible explanations of the apparently smaller number of cases of sorghum poisoning in the Southeastern

States: (1) The quantity of glucoside stored by the plant may be less, (2) the enzyme which exists in the plant and is instrumental in breaking down the glucoside and liberating the prussic acid may be less active in these States, or (3) the HCN may occur in a more unstable form in sorghums grown in the North and West. The first of these explanations seems the more reasonable and further experiments are needed to prove or disprove the theory.

RELATION OF THE HYDROCYANIC-ACID CONTENT OF SORGHUMS TO VARIETAL DIFFERENCES.

No thoro study of this phase of sorghum poisoning has been made by chemists. As noted previously, Willaman and West (22, p. 272) concluded that "varietal difference is probably of more weight in determining the amount of hydrocyanic acid in sorghum than are conditions of growth."

The most impressive series of analyses yet published are those by Collison (4, p. 52). The material for these analyses was collected from plants 12 to 24 inches high and the amount of HCN varied from absolutely nothing in Amber sorgo to 0.0037 percent in Dwarf hegari. The results for the different varieties arranged in order of increasing amount of HCN are as follows: Amber sorgo 0, Orange sorgo .0008, Dwarf milo .0016, Pink kafir .0016, Sunrise kafir .0018, Darso sorghum .0022, Dwarf kafir .0024, Shallu .0026, Brown kaoliang .0031, Feterita .0032, Blackhull kafir .0033, and Dwarf hegari .0037 percent: These percentages are all on the basis of fresh material.

Chemical analyses, especially those of Collison, show a wide range of hydrocyanic-acid content in the ordinary varieties of sorghum. The probable error in such determinations is rather large no doubt and sufficient care is not always used to collect the material from plants of the same size or stage of maturity.

SYMPTOMS OF PRUSSIC ACID POISONING.

Prussic acid is a deadly poison and, when the quantity consumed is sufficiently large, death ensues very quickly, often within 15 minutes. When the amount taken into the system is not large enough to cause immediate death, the animal lives in many cases 4 or 5 hours, usually suffering acutely, and often recovers. The symptoms have been described in detail by Peters (14).

A heifer was turned into a field of sorghum which had previously been responsible for the death of some cattle. Ten minutes after she had begun to eat the sorghum she dropped to the ground and was

watched closely for 3.5 hours. It then became apparent that she would not recover and she was killed in order to make a post-mortem examination. When lying down the heifer's head was turned toward the abdomen as in the case of a horse having colic; the muscles, especially of the nose and head, twitched; the pupils of the eyes were dilated and the eyes gave off a watery discharge; the tongue was partially paralyzed and great quantities of saliva ran from the mouth; the limbs and ears were cold; the pulse not perceptible; and the mucous membrane of the rectum protruded with involuntary discharge of urine and feces. In the last stages the limbs were paralyzed and the animal was unconscious. The mucous membrane of the mouth was of a salmon color.

The post-mortem examination revealed 1.5 pounds of sorghum leaves in the paunch. There was no sourness of the contents of the paunch and the mucous membrane of the intestines was normal as were all other internal conditions of the animal. A particular examination of the pharynx, epiglottis, and esophagus showed that no leaves were lodged in any of these organs. Ten other post-mortems verified this freedom of the throat from obstructions, showing that death does not result from strangulation. The reports of other veterinarians agree in substance with this report of Peters, except that in some cases a slight bloating, which can not be relieved by puncturing the abdomen with a trochar, is said to accompany the poison effects.

REMEDIES FOR PRUSSIC ACID POISONING.

Numerous remedies for this poisoning have been proposed, but an effective safeguard against the poison is hard to devise because it is so quickly fatal. Glucose, dextrose, and other forms of sugar are known to act as antidotes to the poison. Avery found that twice the fatal dose of prussic acid could be given an animal without causing its death if the acid were accompanied by glucose (14). These results of Avery's are so suggestive that they are repeated here in Table 4.

TABLE 4.—*Effect of glucose in lessening the poisonous action of prussic acid.*

Prussic acid administered.	Results.
0.2 gram	Slight symptoms
0.4 gram	Animal very sick, but recovered
0.8 gram in 15 grams glucose	Very slight symptoms
1.6 grams in 30 grams glucose	Animal very sick, had severe convulsions, but recovered

The prussic acid was administered to a barren heifer and sufficient time was allowed to elapse after each treatment for the animal to recover normal condition.

Dowell in his work at the Oklahoma station (6, p. 178) added to the findings of Avery by showing that the presence of even 1 percent of dextrose or maltose in the digestion solution prevented the liberation of about three-fourths of the prussic acid from a sorghum sample. These sugars are both formed by the action of ptyalin on starches in the paunch of an animal and this furnishes a possible explanation of the fact that cattle which are being fed on corn can ordinarily pasture a sorghum field without injury. One way of reducing the danger of sorghum poisoning is to feed the animals some starchy concentrate like corn, kafir, milo, or feterita before turning them on sorghum pasture. Avery's recommendation of the use of glucose in the form of corn sirup and of milk as antidotes to the prussic acid, when it is possible to give them to the animal, is thus supported by experimental evidence.

Haring of the California Agricultural Experiment Station (9) recommends an ever-ready antidote for prussic acid that is used in the cyanide plants of gold mines. It is prepared as follows:

Bottle No. 1.—Select a quart bottle with a long neck suitable for drenching cattle. Place in this bottle one pint of water and one ounce of sodium carbonate (ordinary washing soda will do). Keep the bottle tightly corked.

Bottle No. 2.—Place in this ½ ounce of iron sulphate (copperas) dissolved in a pint of water. Keep tightly corked.

When needed, pour the contents of bottle No. 2 into bottle No. 1, shake, and administer immediately. A cow should receive a quart, and a sheep one-half pint of the mixture. This preparation can be made up in larger quantities if desired so that several animals may be treated at the same time.

In addition to glucose, Francis of the Oklahoma station (8) lists the following remedies: A large dose of some quick acting purgative, such as mixture of Epsom salts and linseed oil; the inhalation of ammonia; peroxide of hydrogen introduced by means of a stomach tube; a combination of 1 to 2 drams of magnesia made into a smooth paste with water and poured down the animal's throat, this to be followed with 16 minims of a solution of iron chlorid and 1.5 grains of ferrous sulfate dissolved in water.

The disadvantage of most of the remedies recommended by Francis is that they require materials which, with the exception of the Epsom salts and linseed oil, are not ordinarily kept on hand by the farmer.[4]

[4] Some of the remedies advocated in farm papers are of interest because they usually consist of materials available in the farm home. One of these which seems to have been born of actual experience is offered by Mrs. C. L.

Baldwin of Hitchcock County, Nebr., in the Nebraska Farmer of March 24, 1915, p. 384. I quote from this issue as follows: "We have a method for treating a cow that has been poisoned on cane which may be of benefit to some one. Place a teaspoonful of soda in a pint of vinegar that has been diluted until it is suitable for a person to take, and drench the animal with this mixture while it is foaming. Half-pint doses, and from one to four of them, is all that we have ever used. Usually one is enough. A small lump of salt is placed in the animal's mouth to keep it open. By this treatment we have never lost a cow when we found them alive. We have saved them after they were unable to move."

Any remedy to be effective must be available for instant use.

LITERATURE CITED.

1. ALWAY, F. J., and TRUMBULL, R. S. On the occurrence of prussic acid in sorghum and maize. *In* Nebr. Agr. Expt. Sta. 23d Ann. Rpt. (1909), pp. 35–36. 1910.
2. BALFOUR, ANDREW. Cyanogenesis in *Sorghum vulgare*. First Rpt. Wellcome Research Lab. at the Gordon Memorial College, Khartoum, pp. 47–48. 1904.
3. BRUNNICH, J. C. Hydrocyanic acid in fodder-plants. *In* Jour. Chem. Soc. (London), v. 83, pt. 2, pp. 788–796. 1903.
4. COLLISON, S. E. Prussic acid in sorghum. Fla. Agr. Expt. Sta. Bul. 155, p. 52. 1919.
5. CRAWFORD, ALBERT C. The poisonous action of Johnson grass. U. S. Dept. Agr., Bur. Plant Indus. Bul. 90, pt. IV, pp. 3–6. 1906.
6. DOWELL, C. T. Cyanogenesis in *Andropogon sorghum*. *In* Jour. Agr. Research, v. 16, no. 7, p. 180. 1919.
7. DUNSTAN, W. R., and HENRY, T. A. Cyanogenesis in plants, Part II. The great millet (*Sorghum vulgare*). *In* Philosophical Trans. Royal Soc. London, ser. A, v. 199, pp. 399–410. 1902. *Abs. in* Proc. Roy. Soc. (London), v. 70, pp. 153–154. 1902.
8. FRANCIS, C. K. The poisoning of live stock while feeding on plants of the sorghum group. Okla. Agr. Expt. Sta. Circ. of Information 38, pp. 1–4. 1915.
9. HARING, C. M. Precautions against poisoning by Johnson grass and other sorghums. Calif. Agr. Expt. Sta. unnumbered Circ., pp. 1–3. 1917.
10. HILTNER, R. S. The fatal effect of green sorghum. Nebr. Agr. Expt. Sta. Bul. 63, pp. 71–84. 1900.
11. MAXWELL, W. Sorghum poisoning. *In* Queensland Agr. Jour., v. 13, no. 5, pp. 473–474. 1903.
12. MENAUL, PAUL, and DOWELL, C. T. Cyanogenesis in Sudan grass: a modification of the Francis-Connell method of determining hydrocyanic acid. *In* Jour. Agr. Research, v. 18, no. 8, pp. 447–450. 1920.
13. PEASE, CAPT. H. T. Poisoning of cattle by *Andropogon sorghum*. *In* Jour. Comp. Med. and Vet. Arch., v. 18, pp. 679–683. 1897.
14. PETERS, A. T., SLADE, H. B., and AVERY, SAMUEL. Poisoning of cattle by common sorghum and kafir corn. Nebr. Agr. Expt. Sta. Bul. 77, pp. 1–16. 1903.

15. Ravenna, C., and Babini, V. On the presence of free hydrocyanic acid in plants, II. Atti R. Accad. Lincei, Rend. Cl. Sci. Fis., Mat. e Nat., 5 ser., 21, I, no. 8, pp. 540–544. 1912.
16. Schröder, Johannes, and Dammann, Hans. Zur Kenntnis der aus verschiedenen Hirsearten Entwickelten Blausäuremengen. *In* Chem. Ztg., Bd. 35, no. 155, p. 1436–1437. 1911.
17. Slade, H. B. A study of the enzyms of green sorghum. *In* Nebr. Agr. Expt. Sta. 15th Ann. Rpt., pp. 55–62. 1902.
18. ——. Prussic acid in sorghum. *In* Jour. Amer. Chem. Soc., v. 25, pp. 55–59. 1903.
19. Willaman, J. J. The estimation of hydrocyanic acid and the probable form in which it occurs in *Sorghum vulgare*. *In* Jour. Biol. Chem., v. 29, no. 1, pp. 25–36. 1917.
20. ——. The effect of anesthetics and of frosting on the cyanogenetic compounds of *Sorghum vulgare*. *In* Jour. Biol. Chem., v. 29, no. 1, pp. 37–45. 1917.
21. —— and West, R. M. Notes on the hydrocyanic-acid content of sorghum. *In* Jour. Agr. Research, v. 4, no. 2, pp. 179–185. 1915.
22. ——. Effect of climatic factors on the hydrocyanic acid content of sorghum. *In* Jour. Agr. Research, v. 6, no. 7, pp. 261–272. 1916.

CROSS-POLLINATION OF MILO IN ADJOINING ROWS.[1]

John B. Sieglinger.[2]

In 1919 Karper and Conner[3] published data showing the amount of natural cross-pollination between white and yellow milo. The two varieties were in bloom at the same time, and each white milo plant was surrounded by plants of yellow milo. Under these conditions, 6.18 percent of cross-pollination occurred.

To determine the amount of cross-pollination occurring in the direction of the prevailing wind between adjoining rows of the same height and blooming at the same time, Standard yellow milo, C. I. No. 234, and Standard white milo, C. I. No. 352, were grown in adjoining plats on the Woodward Field Station in 1919. The yellow milo was south of the white milo in rows running east and west, the prevailing wind being from south to north. These two varieties differ

[1] Contribution from the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication February 11, 1921.

[2] Assistant agronomist in charge of cereal experiments on the Woodward Field Station, Woodward, Okla.

[3] Karper, R. E., and Conner, A. B. Natural cross-pollination in milo. *In* Jour. Amer. Soc. Agron., v. 11, no. 6, pp. 257–259. 1919.

only in seed color. The date of first heading was recorded as August 4 for both varieties and all plants were headed August 22. The date of first heading is recorded as the date when the first heads are fully exserted from the sheath, and the date of full heading as the date when all the main heads are exserted. In the period from August 4 to 22 most of the blooming of the milo occurred, i.e., when the first heads emerged from the boot the flowers at the tip or upper end were starting to bloom and by the time the main heads had fully appeared blooming was about completed. To meet the possible objection that blooming was not completed at this time, wind velocity and direction are shown in Table 1 for a period including seven days after heading ended.

TABLE 1.—*Average hourly velocity and direction of wind at Woodward, Okla., during the period from August 4 to 29, 1920.*

Date, August.	Average velocity, miles per hour.	Direction at 8 a.m.	Date, August.	Average velocity, miles per hour.	Direction at 8 a.m.
4	9.4	S.W.	17	5.2	S.E.
5	7.6	S.W.	18	3.7	N.W.
6	5.6	S.W.	19	6.1	S.W.
7	3.5	S.	20	5.1	S.W.
8	1.6	S.E.	21	5.6	S.W.
9	3.1	S.	22	6.4	S.W.
10	5.3	S.	23	6.3	S.W.
11	8.1	S.W.	24	4.4	S.
12	7.1	S.W.	25	4.0	S.W.
13	4.8	N.E.	26	7.6	S.W.
14	11.8	S.E.	27	9.2	W.
15	4.6	S.W.	28	9.0	S.W.
16	3.5	N.E.	29	6.5	S.W.

Table 1 shows that the wind was from the south, southwest, or southeast practically thruout the blooming period.

All of the main heads on the south row of white milo were saved for use in this experiment. This row of white milo was pure in 1919, as not a single hybrid plant appeared that year. Due to a shortage of land, only 12 heads were sown in separate rows in the field in 1920. Not all the seed from any one head was required to sow one of the rows, which varied from 300 to 320 yards in length. The stand obtained was fair, tho it was not uniform in the different rows. This variation may have been due in part to differences in germination, tho injury by moles was also a factor.

When the milo was ripe counts were made of the total number of plants in each row and of the number of plants producing yellow-seeded heads. The data obtained are shown in Table 2.

TABLE 2.—*Total number of plants, number of plants with yellow seeds, and percentage of cross-pollination in 12 rows of white milo.*

Row No.	Total number of plants.	Number of yellow-seeded plants.	Percentage of cross-pollination.[a]
1	483	23	4.76
2	459	12	2.61
3	437	28	6.41
4	415	22	5.30
5	432	37	8.56
6	355	16	4.51
7	401	27	6.73
8	536	45	8.40
9	413	12	2.91
10	552	15	2.72
11	295	23	7.80
12	347	16	4.61
Total	5,125	276	5.38

[a] Except in row 5, all the hybrids were yellow-seeded. In row 5 there were 4 plants which bore light brown seed. These are not included in the above figures. If these are included, the percentage of cross-fertilization for row 5 would be 9.49 instead of 8.56, changing the average of all rows from 5.38 to 5.46 per cent.

While the numbers here reported are not large enough to be conclusive, they give an indication of the amount of cross-pollination between two varieties of sorghum of the same height and blooming at the same time, when grown in adjoining rows. The percentage shown in Table 2, 5.38 percent, is slightly less than that reported by Karper and Conner, 6.18 percent, from plants of white milo surrounded by yellow milo.

AGRONOMIC AFFAIRS.

ANNUAL MEETING OF THE SOCIETY.

The fourteenth annual meeting of the American Society of Agronomy will be held at New Orleans, La., on November 7 and 8, immediately preceding the annual sessions of the Association of Land-Grant Colleges. As usual, many other agricultural meetings will be held during the week of the college and station meeting. The program will consist of a symposium on teaching farm crops courses, under the direction of Prof. L. A. Call, and a symposium on nitrogen directed by Dr. J. G. Lipman. There will also be a session at which miscellaneous papers will be presented, while the meeting on Monday evening, November 7, will be a joint session with the Society for the

NOTES AND NEWS.

L. C. Aicher, for the past ten years superintendent of the Aberdeen (Idaho) substation, became superintendent of the Hays Branch Station, Hays, Kans., on October 1.

Dr. Elmer D. Ball, assistant secretary of agriculture since June, 1920, has been made director of scientific work in the United States Department of Agriculture, effective October 1. This is a new position provided for in the appropriation act for the department for the current fiscal year. Provision was also made for a director of regulatory work, but this official has not yet been named.

Dr. John Lee Coulter, dean of the West Virginia college of agriculture and director of the experiment station, has been elected president of the North Dakota Agricultural College.

Dr. E. P. Deatrick, formerly instructor in the department of soil technology at Cornell University, is now associate professor of soils and head of the soils department at the West Virginia college of agriculture.

W. J. Green, until recently superintendent of extension on the Island of Guam, is now extension agronomist at the Oklahoma college.

Dr. Frank S. Harris, director of the Utah station, has been elected to the presidency of Brigham Young University at Provo, Utah. He has been succeeded as director by William Peterson, formerly geologist in the Utah Agricultural College.

H. D. Hughes, professor of farm crops in the Iowa college, has been granted a year's leave of absence and is now associated with commercial growers of annual white sweet clover seed in Alabama.

Irving S. Jensen, a 1918 graduate of the Utah college, is now instructor in agronomy in Montana State College.

H. L. Kent, superintendent of the Hays (Kans.) branch station, has been elected to the presidency of New Mexico State College.

A. C. Kuenning, formerly county agent in Dickey Co., N. Dak., is now superintendent of the Williston (N. Dak.) substation.

Clyde McKee, associate professor of farm crops in Iowa, has been elected agronomist of the Montana station and head of the department of agronomy in Montana State College.

G. P. McRostie, recently a graduate student at Cornell University, is now assistant professor of cereal husbandry in Macdonald College, Quebec.

Paul C. Mangelsdorf, a recent graduate of the Kansas college, is now with the New Haven (Conn.) station.

E. G. Montgomery, formerly in charge of foreign marketing investigations for the Department of Agriculture, is now chief of the foodstuffs division of the Bureau of Foreign Commerce, Department of Commerce.

E. O. Pollock, formerly of the farm crops department of the University of Missouri, is now with the Porto Rico college of agriculture.

C. W. Pugsley, editor of the *Nebraska Farmer* and formerly director of extension in the Nebraska college of agriculture, became assistant secretary of the Federal Department of Agriculture on October 1.

Karl S. Quisenberry, recently nursery foreman for the farm crops section of the Kansas station, is now associated with the West Virginia college of agriculture.

W. H. Stevenson, head of the department of soils and crops at the Iowa college and vice-director of the station, has been given a year's leave of absence to become representative of the United States on the permanent council of the International Institute of Agriculture at Rome.

Dr. William E. Stone, president of Purdue University since 1900, fell from a cliff near the summit of Mt. Eanon, Alberta, July 16 and was instantly killed.

H. C. Taylor, chief of the Federal office of farm management, succeeded George Livingston as chief of the Bureau of Markets on July 1, on which date it was combined with the Bureau of Crop Estimates.

Dr. N. I. Vavilov, director of the Russian Bureau of Applied Botany and Plant Industry, made an extended tour of the United States during August and September.

G. F. Warren, professor of farm management at Cornell University, has been granted leave of absence to February 1, 1922, to become consulting specialist in the reorganization of the Federal Bureau of Markets and Crop Estimates.

John B. Wentz, formerly professor of farm crops in the Maryland college, is now associate professor of farm crops in the Iowa college.

The Board of Trustees of Ohio State University has authorized the establishment, within the College of Agriculture, of The Plant Institute of Ohio State University. All members of the staff of the college interested in plant studies may be members, and all graduate students doing their major work with plants are associate members. The Institute will conduct a seminar, review the work of its graduate students, and encourage research, especially the study of such problems as require cooperation. The departments of the college chiefly concerned are botany, horticulture, farm crops, agricultural chemistry, and soils. Thomas G. Phillips is secretary of the institute.

An Italian agronomic society (Società Agronomica Italiana) has been organized, with headquarters at Via dei Crescenzi No. 26, Rome, "with the idea of uniting all branches of science in any way connected with agriculture." Senator B. Grassi, director of the Institute of Anatomy, University of Rome, is president of the society. Among the important problems which are being studied by the society are the best means of utilizing poor and arid lands, with a special study of drouth resistance; influence of physical and meteorological factors on the yield of wheat in southern districts; means of combating insects injurious to the olive; the utilization of the abundant leucite deposits for the production of potash manures; and the causes of the root rot of citrus fruits.

The first report of the council of the National Institute of Agricultural Botany of Great Britain has been received. This institute was organized in the winter of 1917–18 as an outgrowth of the wartime realization of Britain's need for greater food production. The first meeting of the council was held January 21, 1919. Sir A. Daniel Hall, Sir Lawrence Weaver, and Prof. R. H. Biffen are vice-presidents of the Institute and Sir Lawrence Weaver is chairman of the council. W. H. Parker is director of the Institute and chairman of its committee on field trials. Chairmen of other committees are Prof. R. G. Stapledon, grasses and clovers; Sir Lawrence Weaver, potatoes; E. S. Beaven, cereals; and R. N. Salaman, potato synonyms. The institute has headquarters and trial grounds at Cambridge, a 354-acre farm in Huntingdonshire, and a 39-acre potato testing station in Lancashire. One of the important policies of the institute is the rapid increase and dissemination of improved varieties of agricultural plants.

CONFERENCE ON FARM CROPS TEACHING.

Following is the program of the conference on collegiate teaching of farm crops, which was held at the University of Illinois, Urbana, Ill., August 4 and 5.

Thursday, August 4, 9 A.M.

The Kind of Teaching in Farm Crops Suited to Agricultural Students, Dean Eugene Davenport, University of Illinois.

In what year should the elementary course in farm crops be given and what should be its position in the curriculum with reference to the basic sciences? Discussion led by Prof. E. S. Kinney, University of Kentucky.

What should be the nature of the class work in the elementary course in crops, prerequisites and content? Discussion led by Prof. M. L. Fisher, Purdue University.

2 P.M.

What should be the primary object of the elementary course in farm crops: (a) To give an essential instruction in the practical production of crops which would be more or less complete in itself, or (b) to lay the foundation for further studies of the subject? Discussion led by Prof. W. C. Etheridge, University of Missouri.

What part of the elementary course in farm crops should be devoted to laboratory work and what should be the nature of this work? Discussion led by Prof. J. W. Zahnley, Kansas State Agr. College.

The relation of the crops courses taught in vocational schools to the standard of the elementary course in Farm Crops. Discussion led by Dr. W. L. Burlison, University of Illinois.

Friday, August 5, 9 A.M.

The relation of plant physiology and courses in botany to farm crops teaching. Discussion led by Prof. J. F. Cox, Michigan Agri. College.

The advanced undergraduate courses in farm crops—their nature and general characteristics. Discussion led by Prof. J. B. Park, Ohio State University.

Would it be advisable to hold inter-collegiate grain judging contests? Discussion led by Prof. Clyde McKee, Iowa State College.

2 P.M.

Reports of committees.

An inspection of the work in agronomy at the University of Illinois.

JOURNAL

OF THE

American Society of Agronomy

Vol. 13. November, 1921. No. 8.

METHODS OF APPLYING INOCULATED SOIL TO THE SEED OF LEGUMINOUS CROPS.[1]

A. C. Arny and F. W. McGinnis.[2]

Introduction.

The beneficial interrelationship between leguminous crops and certain bacteria in utilizing the free nitrogen of the air has been known since 1886. Since that date various practices in securing inoculation for leguminous crops have been worked out. It has been found that the particular bacteria needed for a certain group of crops may be isolated and increased as pure cultures and so distributed. Various pure cultures have been put out from time to time. The earlier and some of the later attempts in the preparation of pure cultures have not always been entirely satisfactory and hence the soil transfer method has been used very widely. This consists of transferring to the new field and scattering thoroly from 100 to 300 or more pounds of soil per acre from a nearby field which has grown a legume and which is known to have the necessary bacteria present.

Transfer of this amount of soil for each acre in which the plants are to be supplied with bacteria for short distances involves only the labor of hauling and scattering, which is considerable, while for greater distances the additional expense of freight must be considered.

To reduce the expense of the soil transfer method the practice of

[1] Published with the approval of the Director as Paper 223 of the Journal Series of the Minnesota Agricultural Experiment Station, University Farm, St. Paul, Minn. Received for publication December 13, 1920.

[2] Head of section of farm crops and assistant professor of farm crops, respectively, in the Division of Agronomy and Farm Management, Department of Agriculture, University of Minnesota.

sticking to the seed a small quantity of soil containing the necessary organism has been recommended and used widely, apparently without experimental evidence as to the efficiency of the practice as compared with transferring larger quantities of soil. This method consists of moistening the seeds with a weak glue solution and then dusting on a bushel of seed approximately a pound of finely sifted air-dry soil known to contain the desired bacteria. This dries the seed so that it is ready for immediate use. The results secured from the use of this method have been quite variable.

In Minnesota, with the exception of certain areas, alfalfa, sweet clover, and soybeans have not been grown sufficiently up to the present time to eliminate the necessity for supplying the proper bacteria to new sowings. Results from the use of commercial inoculants had not been satisfactory. To obviate handling large amounts of soil the glue method was used and results were non-uniform. Therefore, it was determined to secure comparative data on various practices in connection with the inoculation of these leguminous crops. The various phases may be outlined as follows:

1. Comparison of amounts of soil adhering to a bushel of seed, using water only and various concentrations of glue and sugar.
2. Comparison of thoroness of inoculation on different soils where the seed was treated in different ways.
3. Comparison of value of old and fresh inoculating material and the effect of exposure of the treated seed to the sunlight.

Review of Literature.

The thoroness of inoculation of leguminous plants as indicated by the appearance of nodules on their roots and color and vigor as compared with uninoculated plants grown under the same conditions depends upon several factors.

The number of vigorous bacteria per seed sown does not appear to have much influence, according to Fellers (4)[3], within certain rather wide limits. However, in another experiment the addition of more bacteria than were carried on the seed gave additional numbers of nodules per plant with soybeans and alfalfa. The same author states (3) that where the number of cells in commercial cultures ran below 1,000,000 per cubic centimeter the results were not usually satisfactory.

Noyes and Cromer (12) used both a half and 1 pound of soil per acre for inoculating various leguminous seeds in comparison with several commercial inoculants. The amounts used gave satisfactory results with sweet clover, but for cowpeas, soybeans, and hairy vetch the

[3] Reference is to "Literature cited," page 303.

inoculation was practically nil. Double the amount of commercial inoculant used in the first experiment gave in a succeeding experiment with soybeans 75 percent inoculation as compared with 20 percent for the check. From this work the authors conclude that larger quantities of both commercial cultures and soil than were used would be necessary to give satisfactory inoculation.

An examination of a number of commercial cultures by Temple (13) showed for the most part sufficient numbers of bacteria in the amount put up for a given area to bring about satisfactory inoculation.

Hopkins (6) advised gathering soil to a depth of from 3 to 4 inches from fields growing the same kind of legume crop, the plants of which upon examination are found to have nodules on their roots, and scattering this broadcast at the rate of a few hundred pounds per acre at the time the new field is to be seeded. Later (7) the following directions were given: "Moisten the seed with a 10 percent glue solution (1 pound of furniture glue to 1 gallon of water) and immediately sift over them sufficient dry pulverized infected soil to absorb all of the moisture, thus furnishing a coating of infected soil for every seed."

Satisfactory results with commercial inoculation, but still better from the application of 200 pounds of soil per acre from an old alfalfa field, are reported by Arny and Thatcher (1). The numbers of bacteria supplied by each of the two methods were not checked.

There appears to be a difference in the ease of inoculation of the different crops. Noyes and Cromer (12) found soybeans, cowpeas, and hairy vetch free from nodules under the same conditions that gave good inoculation of sweet clover.

Fellers (3) found more commercial cultures for soybeans ineffective than for other crops and recommends the soil transfer method for this crop unless the commercial cultures are known to be of good quality.

Moisture conditions in the soil influence the number of nodules produced on plants. A water content in the soil of 75 percent is reported by Wilson (14) as giving more nodules per 100 plants than a water content of 65 percent and considerably more than a water content of 25 percent.

Noyes and Cromer (12) secured a higher percentage of inoculation on brown silt loam than on sand for both the checks and the plats receiving barnyard manure. The presence of various substances in the soil may affect the percentage of inoculation, nitrate of soda tending to reduce it.

Fred and Graul (5) found that alfalfa responded to inoculation to a greater extent on Plainfield sand than on Colby silt loam. Clover responded to treatment only on the Plainfield sand.

Nitrates and sulfates applied in experiments made by Wilson (14) in amounts which inhibited nodule formation did not reduce the ability of these bacteria to produce nodules when brought under suitable conditions. Nitrogenous compounds were found to be local in character in their effect on inhibiting nodule formation. Carbon-containing compounds in soil cultures stimulated nodule formation. Mention is also made that the composition of the soil solution is a factor in controlling nodule formation.

Nobbe and Richter (10) found that where there was considerable soluble nitrogen in the soil the amount of atmospheric nitrogen fixed by bacteria working in connection with leguminous plants was less than in soils with less nitrogen available.

Moore (9) states that various external conditions such as heat, moisture, alkalinity, amount of nitrogen in soil, etc., may have a direct influence on nodule formation.

Fellers (4) treated alfalfa seeds with gum tragacanth and inoculated them with nodule infusion. He concludes from the experimental data that the gum tragacanth probably aids to some extent in protecting the bacteria, but not enough to justify its use.

Magoon and Dana (8) state that they can see no advantage from the use of glue used to cause soil particles to adhere to the seed. They suggest that, since glue is usually heavily infested with bacteria of various kinds, antagonism of types may cause destruction of the nitrogen-fixing forms.

The effect of exposure of the seed after treatment or of storing it for a time previous to sowing has been considered by several workers. Chester (2) concludes that the legume bacteria perish very rapidly when dried on the seed. Fellers (4) found the greatest decrease in numbers of bacteria on seeds during the first few hours after inoculation, with a relatively slow and uniform decrease up to six months. From the results secured the author concludes that storing the seed several days to a month after applying the inoculant should do no great harm. The seeds would necessarily need to be stored in a suitable place.

Temple (13) stored inoculated field pea seed in a loosely stoppered bottle and made sowings at intervals of 30 days. Nodules were secured on all sowings up to the fifth month.

Nobles (11) exposed small amounts of soil containing nitrogen-fixing bacteria to the sunlight for different periods. At the end of 15 minutes' exposure only 18.9 percent in the sandy soil and 46.3 percent in a compost remained alive. After 7 hours' exposure only 0.5 percent was found alive.

Material and Methods.

In all of the different trials reported seed handled and stored in the ordinary manner was used without sterilization. Seed of the Chestnut soybean, Grimm and common alfalfa, and biennial white sweet clover were used.

Dry furniture glue was used in making up the solutions of this material. The sugar solution was used to avoid any substances in the glue which might be undesirable. Granulated white sugar was used. During ordinary times the small amounts needed would not be prohibitive if results warranted its use.

Tests were made both in the greenhouse and in the field. A white sand sterilized by steam was used in gallon jars in the greenhouse tests only. Here the required nutrients were supplied. A sandy soil from Coon Creek, in Anoka County, was sterilized and used in 6-inch pots in the greenhouse, but the growth of the soybean plants was so abnormal that the tests were considered unsatisfactory. Tests were made using the black loam from University Farm without sterilization in the greenhouse. The sandy soil at Coon Creek is decidedly acid in reaction and the black loam at University Farm slightly so. Previous tests had indicated that these soils were practically free from the bacteria which work in symbiotic relationship with the crops used.

The soil used for inoculating purposes was taken from fields on University Farm which had recently produced crops, the plants of which were well inoculated, as indicated by an abundance of nodules on their roots. It was dried without exposure to sunlight and put thru a very fine sieve. When used it was very much like fine road dust. The seed was moistened, spread out, and the fine soil dusted over it. The seed was used immediately unless otherwise indicated. The commercial inoculant used was a commercial culture.

Little difficulty was experienced in the majority of instances in distinguishing, by the location and number of nodules on the roots, the difference between the chance inoculation of the checks where this occurred from the condition where the bacteria were supplied.

In the greenhouse tests the plants were thinned to ten per jar or pot. In the field, seed given the various treatments was sown in replicate rod rows 1 foot apart.

Unless otherwise indicated in the field trials, 50 soybean plants and 100 alfalfa plants were dug, the moist soil carefully removed, and the number of nodules on each plant counted. In all probability some of the nodules were removed with the soil and therefore were not included in the count.

Interpretation of Results.

In order to secure data which might aid in the interpretation of the results of the experiments, 200 6-inch pots were filled with black loam soil from University Farm, placed in the greenhouse, and sown with alfalfa seed treated in four ways. There were 50 pots each sown with seed to which inoculated soil was made to adhere with 20 percent glue and sugar solutions, and a like number each with the same weight of inoculated soil applied as seed used and with a commercial culture applied to the seed in the usual way. The seeding was done on May 7, 1920. When the plants were large enough, the number in each pot was uniformly reduced to ten. On August 11 the contents of each pot was turned out, the roots washed from the soil with a gentle stream of water, and the number of nodules per 10 plants counted, with the results shown in Table 1.

Table 1.—*Number of nodules per pot of ten plants, number of nodules per plant and the variation in the number of nodules per plant grown in the greenhouse from alfalfa seed variously treated.*

Method of inoculation.	Number of pots.	Variation in number of nodules per 50 pots.	Average number of nodules per pot.	Average number of nodules per plant.
Glue solution and soil	50	12.2	46.7	4.07
Sugar solution and soil	50	18.8	47.3	4.73
Same weight of soil as seed	50	18.8	50.9	5.09
Commercial culture	50	41.6	102.0	10.20
Average	50	22.85	61.76	6.176

Considering all the pots in the test, the average number of nodules per pot is 61.76. The percentage of variation for the test was found by the pairing method to be 17.29. Considering 50 pots of each treatment, the variation in number of nodules per pot is 1.5106. Accepting 30 to 1 as the lowest odds which may be considered reasonably certain, the least significant difference between the average number of nodules in the pots of any two treatments is 5.74. Using this figure in a broad way in the interpretation of the results of this test, the glue, sugar, and soil methods may be considered equally good. Likewise, the commercial culture may be considered as giving better results than any one of the other methods. The figure, 5.74, derived from the results of this trial, where a comparatively large number was considered, may be used to advantage in the interpretation of the results in the main experiments.

THE GLUE METHOD ON TRIAL.

To try out the efficiency of the various methods commonly used in inoculating seed, 5-percent solutions of glue and sugar were made up and soil made to adhere to seed by their use. Likewise, seed was treated with a commercial culture in the ordinary way. This variously treated seed, together with seed to which the same weight of soil was added at seeding time, was sown in five pots each of University Farm soil in the greenhouse on June 7, 1919. The crop used was soybeans. On July 26 five additional pots of each treatment were made up for both soybeans and alfalfa. The plants were thinned to 10 per pot and on the dates indicated the contents of each pot were turned out and the roots washed free from soil by using water. The results are given in Table 2 in the form of number of nodules per plant.

TABLE 2.—*Number of nodules per plant for soybeans and alfalfa in greenhouse trials from seed variously inoculated.*

Crop and method of inoculation.	First trial, soybeans only, sown June 7, read Aug. 28.	Second trial, soybeans and alfalfa, sown July 26, read Sept. 25.
SOYBEANS:		
No inoculation	4.8	0.35
Glue solution and soil	6.1	4.80
Sugar solution and soil	8.1	4.20
Equal weights of soil and seed	20.8	6.90
A commercial culture	10.2	12.00
ALFALFA:		
No inoculation	...	1.70
Glue solution and soil	...	10.70
Sugar solution and soil	...	10.60
Equal weights of soil and seed	...	17.60
A commercial culture	...	25.00

In the greenhouse tests with soybeans the controls showed an abnormally high inoculation. This probably makes the test of little or no value. In the second test a commercial culture was the most effective.

With the alfalfa both the glue and sugar solutions with soil gave satisfactory inoculation. However, where soil equal in weight to the seed and the commercial culture were used decidedly higher numbers of nodules per plant were secured.

In addition to these seedings in the greenhouse, the work was extended to the field, where four regularly distributed rod rows 1 foot apart were sown at University Farm and on the peat at Coon Creek. On the dates indicated in Table 3, 50 plants from each row of soybeans and 100 plants from each row of alfalfa and sweet clover were carefully dug and read, the results being given in percentage of plants

inoculated. Any plant bearing one or more nodules was read as inoculated. It is appreciated that some nodules may have been lost because of the technique which was necessarily followed in the reading.

TABLE 3.—*Average percentage inoculation of soybeans, alfalfa, and sweet clover plants in field trials on University Farm and on Coon Creek peat from seed sown August 7, 1919, as shown by readings on the dates indicated.*

Crop and method of inoculation.	Location and dates of readings.				
	University Farm.		Coon Creek peat.		
	Sept. 24.	Oct. 20.	Sept. 10.	Sept. 25.	Oct. 10.
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Percent.*
SOYBEANS:					
No inoculation	1.6	0	0	1.0	0
Glue solution and soil	16.5	31.3	4.5	11.7	15.5
Sugar solution and soil	28.0	28.0	19.0	22.0	46.7
Same weight of soil as seed	80.5	80.5	68.7	93.0	81.7
A commercial culture	89.0	89.0	93.9	95.7	97.3
ALFALFA:					
No inoculation	2.5	5.5	0	2.0	3.0
Glue solution and soil	10.0	19.0	11.7	18.3	25.0
Sugar solution and soil	10.0	10.0	13.0	15.0	20.0
Same weight of soil as seed	11.3	27.0	33.2	36.3	73.3
A commercial culture	19.0	52.0	38.4	42.7	75.3
WHITE SWEET CLOVER:					
No inoculation	2.5	7.0	0	2.3	3.7
Glue solution and soil	11.0	11.0	35.6	40.7	74.0
Sugar solution and soil	10.0	18.0	43.1	46.0	76.7
Same weight of soil as seed	12.0	42.0	85.9	91.0	98.1
A commercial culture	39.0	62.0	91.5	98.0	98.6

In the field trials with soybeans the larger amount of soil and the commercial culture appear to have given the higher percentage of inoculation at both locations on the first readings, and this difference held reasonably well thru the second reading made 74 days from sowing at University Farm and for the second and third readings made 49 and 64 days from the date of sowing on the Coon Creek peat.

The control seedings of both alfalfa and sweet clover show a somewhat higher percentage of plants bearing nodules than the soybeans, but in every instance they could be easily recognized by comparison as chance inoculations. Here, again, on the peat the same weight of soil as seed and the commercial culture are superior to the other two methods of inoculation on the first reading, and this advantage is maintained at each of the two later dates.

At University Farm the percentage inoculation for the plants where the same weight of soil as seed was used appears to have given no higher percentage of inoculation on the first date than the other two

methods of using soil. However, there appears to have been a more rapid increase in the percentage at the second date than for the other two methods involving the use of soil. The commercial culture appears to have given a higher percentage of inoculation here at both the first and second readings.

In general at the time of the year the sowings were made there appears to be a more thoro inoculation of the plants in the peat than in the mineral soil.

The appearance of the plants with regard to thrift correlated rather closely with the results as given in the tables. The appearance of the plants where soil of the same weight as the seed was used and the plants inoculated by use of the commercial culture were generally larger and darker green in color than the plants which were from seed treated in the other two ways. The checks in most instances showed a definite lack of inoculation.

RELATION OF CONCENTRATION OF SOLUTION TO SOIL ADHERING TO SEED.

In the foregoing experiments only one strength of solution was used and the amount of soil adhering to the seed was not determined.

In order to ascertain how much of the air-dry sifted soil adhered to the seed when sugar and glue solutions of various concentrations were used as compared with moistening the seed with water only, a number of pound lots of alfalfa and soybeans were weighed. These lots were moistened one at a time with water and the various solutions of sugar and glue and weighed amounts of the soil applied. After a thoro mixing, suitable sieves were used to separate the soil from the seed with the soil particles adhering. With the soybeans there was no difficulty in making this separation, but with the alfalfa, on account of the small size of the seeds, the separation could not be made as sharply, and considerable unattached soil was left with the seed. The results given in Table 4 are the average for two trials in all instances except with the water, where only one trial was made.

It is appreciated that the amounts of soil adhering may be influenced to a considerable extent by the degree to which the seed was moistened and the fineness of the soil. However, with conditions as uniform as possible for all lots, a tendency appears for the stronger solutions to cause additional soil to adhere to soybeans. With alfalfa the difficulty of separating the unattached soil from the seed with the soil particles attached probably masked any real effect of the different strengths of solutions. In no instance was the amount as low as a half pound or 1 pound of soil per bushel of seed, which were the amounts used by Noyes and Cromer with unsatisfactory results.

TABLE 4.—*Comparison of the amounts of dry, finely sifted soil adhering to seed of soybeans and alfalfa seed moistened with water and solutions of sugar and glue of various strengths.*

Material used in moistening seed.	Pounds of dry soil adhering per 60 pounds of seed. Soybeans.	Alfalfa.
Water only	4.3	9.5
Sugar, 5 percent solution	4.5	6.6
Sugar, 10 percent solution	5.3	5.1
Sugar, 20 percent solution	6.7	9.0
Sugar, 30 percent solution	8.8	12.6
Glue, 5 percent solution	3.6	7.2
Glue, 10 percent solution	3.0	9.6
Glue, 15 percent solution	4.8	8.5
Glue, 30 percent solution	5.6	7.5

RESULTS OF THE USE OF SOLUTIONS OF VARIOUS CONCENTRATIONS IN GREENHOUSE AND FIELD TRIALS.

In order to ascertain the effectiveness of the inoculation when solutions of sugar and glue of various concentrations as compared with water only were used to cause soil to adhere to seeds, greenhouse and field sowings were made immediately after the seed had been treated unless otherwise indicated. The greenhouse trials were started October 10, 1919, and read March 26, 1920. The field trials were sown in replicated rod rows on the Coon Creek peat and on adjacent light sandy soil May 6 and 7 and read July 7 and 8 and August 20, 1920, respectively. In the greenhouse trial the sandy soil was sterilized by steam before sowing the seed. The soybean plants on this soil were very abnormal in growth. The alfalfa was somewhat adversely affected by this soil treatment, but to a less extent than the soybeans.

In the greenhouse trials with soybeans the inoculation was not satisfactory in the loam soil at the expiration of 166 days. The plants looked fairly thrifty, with some advantage in favor of the inoculated plants. On the sterilized sand no inoculation could be found on the plants which remained alive after 166 days. Sterilization of the soil and unsatisfactory growth probably accounts for the results. The results reported for soybeans in Table 2 were secured from plants grown in the greenhouse during the summer. The growth of the plants and the inoculation were more satisfactory than that of those grown in the winter. On the loam soil in the greenhouse all of the alfalfa grew well and showed satisfactory inoculation at the end of the 166-day period. On the sterilized sandy soil the growth of the alfalfa was less satisfactory and there was a smaller number of nodules per plant than on the loam soil.

In these greenhouse trials, with the exception of the alfalfa on the

loam soil and the alfalfa treated with glue on the sterilized sandy soil, where there may be some correlation between the concentration of the solution used and the number of nodules per plant, there appears to be little justification for using the more concentrated solutions.

TABLE 5.—*Number of nodules per plant from various methods of inoculation.*

Crop and treatment.	Greenhouse trial.		Field trial.		
	Loam,	Sand,	Peat.		Sand,
	166 days.	166 days.	62 days.	106 days.	62 days.
SOYBEANS:					
No inoculation	0	0	0	0	0
Water and soil	not included		.4	.4	.1
5% sugar solution and soil	.1	0	1.0	1.3	.4
10% sugar solution and soil	.8	0	.1	.3	.9
20% sugar solution and soil	1.2	0	1.3	.6	1.4
30% sugar solution and soil	.5	0	1.0	1.7	1.9
5% glue solution and soil	1.0	0	.4	.8	.7
10% glue solution and soil	.5	0	.8	1.2	.1
15% glue solution and soil	.5	0	.1	1.6	.2
30% glue solution and soil	1.2	0	.6	.5	1.4
Equal weights soil and seed	not included		3.4	2.6	4.2
Commercial culture	do		.1	.3	.1
ALFALFA:					
No inoculation	0	2.2	0	0	0
Water and soil	not included		.6	.6	0
5% sugar solution and soil	19.6	15.8	1.2	.8	0
10% sugar solution and soil	28.7	13.2	.4	.5	0
20% sugar solution and soil	33.9	12.2	2.0	2.6	0
30% sugar solution and soil	39.0	6.6	1.5	1.7	0
5% glue solution and soil	24.7	8.1	1.1	.7	0
10% glue solution and soil	18.4	8.1	.5	1.0	.1
15% glue solution and soil	29.2	17.3	.3	.4	0
30% glue solution and soil	39.1	19.8	.5	.7	0
Equal weights soil and seed	not included		4.0	5.6	.5
Commercial culture	do		6.9	7.6	4.0

In the field trials with soybeans there was little difference in the number of nodules per plant on the peat and sandy soil at the end of 62 days, when the first reading was made. An abundance of rain during this period provided ample moisture for growth even in the sandy soil. At the end of 106 days the number of nodules per plant on the peat was approximately the same as at the first reading. On the sand no readings could be made, due to the extreme drouth which had prevailed during practically the entire period between readings.

Altho the number of nodules for the method where the same weight of soil as seed was used averages somewhat higher than that for the other soil method, there is not a significant difference if the figure 5.74 is used as the measure. However, observations later in the season showed that this was the only satisfactory method of inoculation as indicated by the growth and thrift of the plants.

In this trial with the soybeans the commercial culture did not give satisfactory results. Other inoculations with material from the same lot of the commercial culture were made with negative results.

On the peat soil inoculation of alfalfa, with the exception of the commercial culture and the method where a weight of soil equal to that of the seed was used, gave a low average number of nodules per plant at both the first and second readings. On the sandy soil, even with moisture conditions very favorable during the period up to the first reading, scarcely any indications of inoculation could be found except where soil to the same weight as seed and where the commercial culture were used. Later in the season the plants where these two methods had been used were observed to be dark green in color and of satisfactory growth as compared with the plants in the controls and where the other methods of inoculation had been employed.

Effectiveness of Inoculation as Influenced by Delay in Sowing after the Inoculant has been Applied.

On July 5, 1919, inoculation was applied to the seed of the soybeans and alfalfa. Five percent glue and sugar solutions were used to cause the soil to adhere to the seed. The commercial culture was applied in the usual way. Some of the dry soil was retained to use in applying the same weight of soil as seed at seeding time where that method was used. The seed was sown in white sand sterilized by steam and supplied with the necessary plant food, in sandy soil from Coon Creek sterilized by steam, and in a loam soil from University Farm.

No sowings were made when the inoculant was first applied to the seed. On July 16 a sowing was made in the white sand. Sowings were made in the white sand as well as on the two soil types on October 10. At the same time sowings were made of seed which had been inoculated on October 10 with glue and sugar solutions to cause the soil to adhere. The results are shown in Table 6

With the soybeans, particularly on the white sand, there appears to be a falling off in the efficiency of inoculation due to storing the seed 86 days after the first seeding. Taking into consideration results reported in other tables, storing the seed 16 days did not lower the efficiency of inoculation to any appreciable extent. On the loam soil both fresh inoculation and inoculation applied 102 days previous to sowing gave rather unsatisfactory results. On the sterilized sandy soil the results were variable, largely due to the unsatisfactory growth of soybeans on soil treated in this way.

The results with alfalfa indicate that storing the seed 86 days follow-

ing the first sowing on the white sand, at which time it had been stored 16 days, did not lower the efficiency of the inoculant for plants grown in this material. On the loam soil there appears to have been no diminution of inoculating power due to storage of the seed 102 days after the inoculant was applied. On the sterilized sandy soil the results with alfalfa were more uniform than with soybeans. The results from the seed stored after the inoculant was applied appear to be no lower than where the sowing was done immediately following this operation.

TABLE 6.—*Number of nodules per plant of soybeans and alfalfa when grown in greenhouse trials from seed stored after inoculation.*

Crop and method of inoculation.	Material in which the plants were grown, dates of inoculation, sowing, and reading.					
	White sand.			Loam soil.	Sandy soil.	
	Inoculated July 5, sown July 21, read Sept. 25.	Inoculated July 5, sown Oct. 10, read March 28.	Inoculated July 5, sown Oct. 10, read March 28.	Inoculated and sown Oct. 10, read March 26.	Inoculated July 5, sown Oct. 10, read March 25.	Inoculated and sown Oct. 10, read March 25.
SOYBEANS:						
No inoculation	0	0	0	0	0	0
5 percent sugar and soil	5.0	1.2	.8	.1	3.5	0
5 percent glue and soil	4.0	1.0	.9	1.0	0	0
Equal weights seed and soil	7.8	1.7	3.6	not included	0	not included
A commercial culture	16.7	1.7	3.1	do.	2.5	do.
ALFALFA:						
No inoculation	.2	2.5	2.2	3.5	1.4	2.2
5 percent sugar and soil	7.1	5.6	34.3	19.6	1.8	15.8
5 percent glue and soil	5.5	5.5	29.2	24.7	2.9	8.1
Equal weights seed and soil	9.1	7.7	20.6	not included	5.1	not included
A commercial culture	15.0	16.2	44.0	do.	4.9	do.

These results are similar to those secured by other experimenters. They appear to justify the conclusion that storing seed in a suitable place for a few days to a month or even for a longer period does not reduce seriously the effectiveness of the inoculant.

INFLUENCE OF EXPOSURE OF INOCULANT TO SUNLIGHT.

Finely sifted soil and a commercial inoculant were spread out thinly and exposed to October sunlight for a half hour and five hours. The soil was then applied to the seed, using a 5 percent sugar solution. In applying the commercial culture directions were followed. The seed was sown October 10 and the roots washed out and the results read March 28. These results are presented in Table 7.

TABLE 7.—*Number of nodules per plant where inoculant was exposed to sunlight.*

Treatment.	Soybeans.	Alfalfa.
Soil not exposed	0.1	19.6
Soil exposed one-half hour	.1	16.4
Soil exposed five hours	.9	10.7
Commercial culture not exposed	2.4	29.0
Commercial culture exposed one-half hour	2.7	16.9

The results with the soybeans were not satisfactory, being probably influenced by growing conditions in winter in the greenhouse. With the alfalfa, satisfactory inoculation was secured in each instance. However, exposure of soil for five hours and of the commercial culture for a half hour appears to have reduced materially the number of nodules per plant as read 167 days after the application.

SUMMARY.

1. Five-percent solutions of glue and of sugar and the use of water only caused approximately 4.5 to 5 pounds of dry, sifted soil to adhere to a bushel of soybean seed. Twenty-percent solutions of these two materials caused somewhat more to adhere and 30-percent solutions caused the adherence of 5 6 to 8.8 pounds of soil to the bushel.

2. For alfalfa seed the effect of the different concentrations of these solutions in causing soil to adhere to the seeds was probably masked by the inability to separate thoroly the loose soil particles from the seeds with the soil particles adhering. The amount of soil adhering per bushel of seed varied from 5.1 to 12.6 pounds.

3. Inoculation varied with the crop, the soil, and growing conditions.

4. On sterilized sandy soil the growth and inoculation of soybeans in the greenhouse were not satisfactory. Alfalfa was affected less seriously.

5. With a few exceptions, the plants where water only or glue and sugar solutions of various strengths were used with soil as the inoculant were found to have few, small, and scattering nodules, or none. The plants were uneven, many having the same appearance as the plants in the controls. This method of inoculation is not recommended.

6. The same amount of soil as seed, with one or two exceptions, gave satisfactory inoculation as indicated by the appearance of large nodules grouped about the upper part of the tap root, particulary in the soybean plants, and a dark, green thrifty growth above ground.

7. The commercial culture, with the exception of one field trial and a subsequent greenhouse trial of the same lot of the inoculant with soybeans, gave results similar and frequently more marked than from the use of the same amount of soil as seed.

8. With the exception of one trial with soybeans, storing the seed in a suitable place for a short time after the inoculant was applied did not result in a serious lowering of the number of nodules per plant.

9. Exposure of the soil to the sunlight of an October day for a half hour or for five hours and exposure of the commercial culture for a half hour did not alter the efficiency of these inoculants for soybeans. Exposure of the seed to the more intense heat of spring or summer sun might have produced different results. For alfalfa there appears to have been some reduction in efficiency where the soil was exposed for five hours and where the commercial culture was exposed a half hour. Apparently there was less injury by exposure than may usually be expected. It is recommended that exposure be avoided wherever possible.

Literature Cited.

1. Arny, A. C., and Thatcher, R. W. The effect of different methods of inoculation on the yield and protein content of alfalfa and sweet clover. *In* Jour. Amer. Soc. Agron., 7: 172–185. 1915.
2. Chester, F. D. The effect of desiccation on root tubercle bacteria. Del. Agr. Expt. Sta. Bul. 78, p. 1–16. 1907.
3. Fellers, C. R. Report on the examination of commercial cultures of legume-infecting bacteria. *In* Soil Science, 6: 56–67. 1918.
4. ——. The longevity of *B. radicicola* on legume seeds. *In* Soil Science, 7: 217–232. 1919.
5. Fred, E. B., and Graul, E. J. The gain of nitrogen from growth of legumes on an acid soil. *In* Wis. Agr. Expt. Sta. Research Bul. 39, p. 1–42. 1916.
6. Hopkins, C. G. Nitragin bacteria and legumes. Ill. Agr. Expt. Sta. Bul. 94, p. 306–328. 1904.
7. ——. Science and sense in the inoculation of legumes. Ill. Agr. Expt. Sta. Circ. 86, p. 1–7, 2d ed. rev. April, 1913.
8. Magoon, C. A., and Dana, B. F. Preparation and use of pure cultures for legume inoculation. Wash. Agr. Expt. Sta. Bul. 149, p. 1–16. 1918.
9. Moore, George T. Soil inoculation for legumes. U. S. Dept. Agr., Bur. Plant Indus. Bul. 71, p. 1–72. 1905.
10. Nobbe, F., and Richter, L. Über den Einfluss des im Kulturboden vorhandenen assimilierbaren Stickstoffs auf die Aktion der Knöllchenbactieren. *In* Landw. Vers. Stat., 59: 167–174. 1903.
11. Nobles, Charles. Spring inoculation of legumes. *In* Mich. Agr. Expt. Sta. Quarterly Bul., 1: 91–145. 1919.
12. Noyes, H. A., and Cromer, C. O. Tests of commercial cultures for legume inoculation. *In* Soil Science, 6: 69–79. 1918.
13. Temple, J. C. Studies of *Bacillus radicicola*. Ga. Agr. Expt. Sta. Bul. 120, p. 67–80. 1916.
14. Wilson, J. K. Physiological studies of *Bacillus radicicola* of soybean and of factors influencing nodule formation. N. Y. Cornell Agr. Expt. Sta. Bul. 86, p. 367–413. 1917.

A PLAN FOR THE CONDUCT OF FERTILIZER EXPERIMENTS.[1]

W. J. SPILLMAN.[2]

It is a fundamental principle in experimental work that in order to learn the effect of a causal factor we must vary that factor while keeping all other causal factors constant. The results obtained from a series of fertilizer plats in which no account is taken of this principle can not, in general, be interpreted. A plat is of practically no value in a series unless it can be compared directly with others, and such comparison can not be made when two plats differ in more than one particular. Difference in the quantity of a mixture may be regarded as a single difference, altho it involves differences in more than one fertilizer element. In order to give results of the greatest value, a series of fertilizer experiments must also be planned so as to recognize the fact that the behavior of a fertilizer ingredient depends on the relative amounts of other fertilizer elements available to the growing crops.

It is possible, with a relatively small number of plats, to obtain results that will not only be susceptible of definite interpretation, but will give reliable indications as to the results that would be obtained by the use of more or less of a given element than is actually used in the experiment. This phase of the subject will be discussed at some length in the latter part of this paper.

In the accompanying tables will be found three different series of plats, each serving a different purpose in experimental work. Series I, the most complete of the three, is adapted to research work on the relative effect of different quantities of a fertilizer and of the various fertilizer elements in different combinations. This series involves every possible relation between two, one, and no units of each of the three elements, nitrogen, phosphorus, and potassium. The results also include all the practical results of both the other series. Every plat in Series I is directly comparable with from six to fourteen other plats. In the case of each of the three elements nine 3-term comparisons are possible. These are given in the tables. In the case of each pair of elements three such comparisons are possible, and in the case of the three elements used together there is one 3-term comparison. These are all given in the tables.

Series II is similar in purpose to Series I, but is designed for use in regions where it is already known that one of the three elements is distinctly more of a limiting factor than the other two. As outlined,

[1] Received for publication December 10, 1920.

[2] Associate editor of the Farm Journal, Philadelphia, Pa.

phosphorus is assumed to be this limiting factor. This series is derived from Series I by dropping out all those plats (except two mentioned below) in which the amount of either nitrogen or potash is relatively greater than the amount of phosphorus. The plat receiving a unit of nitrogen (plat 2, Series II) and the one receiving a unit of potash (plat 10, Series II) are retained, since each of them increases by two the number of three-term comparisons that can be made in this series.

To adapt Series II to a region in which some other element is the principal limiting factor, all that is necessary is to put the symbol of that element in the place occupied by the symbol P in the tables and put the symbol P in the place thus vacated. The smaller number of plats in this series should commend it to experimenters whose primary object is immediate practical results. Fewer comparisons are possible than in Series I, as shown in the outline of such comparison in the tables, but the number is sufficient to permit important conclusions.

Series III is designed for the use of farmers who want to experiment on their own farms. Experimenters with limited funds might use this series to advantage. As outlined, it assumes that phosphorus is the principal limiting factor, and that potash is a more important ingredient of fertilizers than is nitrogen. Both these conditions hold in the long-time experiments at the Pennsylvania and Ohio stations and are probably quite general in a large part of this country. The one comparison with potash is designed to show how much of this element may be profitably used along with phosphorus. The one comparison with nitrogen is designed to show how much nitrogen may be profitably used along with phosphorus and potash. The phosphorus comparison is designed to give a line on the quantity of this element that can be used with profit.

Series III may be adapted to a region in which the elements bear a different relation to each other by placing the symbol of the most important element over the middle column, that of the next most important over the last column, and that of the least important over the first column in the outline of the series and of the comparisons to be made with the experimental results.

The figure 1 occurring in the columns of the various tables signifies the use on the plat in question of such quantity of the element the symbol for which heads the column as will be equivalent to an annual application of the following quantities of fertilizer materials per acre:

50 pounds of 16 percent nitrate of soda,
60 pounds of 16 percent acid phosphate, or
40 pounds of 50 percent muriate of potash.

These are here designated as unit applications. The figure 2 signifies the use of twice these quantities.

CHECK PLATS.

In Series I each group of fertilized plats is preceded and followed by a check plat receiving no fertilizer. The first group consists of two plats (Nos. 2 and 3), the other groups of three plats each. In Series II there are fifteen fertilized plats, arranged in groups of three, each group being preceded and followed by a check plat. Only one check plat is inserted in Series III, as farmers will generally not take the trouble to use check plats after the manner of the experimenter. In the hands of a well-trained experimenter other check plats might well be inserted in this series, say, one following plat 7, and one between plats 3 and 4.

Perhaps the best method of using check plats in determining the increase in yield due to fertilizers is that used at the Ohio station. It is as follows:

The "check yield" of a plat is the yield that plat would presumably have made had it received the same treatment as the check plats. In what follows it is assumed that the plats, including check plats, are numbered consecutively. To find the check yield of a plat, subtract the number of the preceding check plat from the number of the plat in question; divide the remainder by one more than the number of plats between the preceding and following check plats; multiply the quotient by the difference in yield of these two check plats; then add this product to the yield of the preceding check plat (subtract if the next check plat yields less than the preceding one). The final result is the "check yield" of the plat in question.

To find the increase in yield due to the fertilizer on a given plat, subtract its check yield from its actual yield. Increases arrived at in this manner are comparable for all the plats.

CORRECTED YIELDS.

It is often desirable to compare directly the yields of all the plats in a series (not merely the increases due to fertilizers). The yields may be reduced to a comparable basis as follows: Multiply the actual yield of each (fertilized) plat by the average yield of all the check plats and divide the product by the check yield of the plat in question. The result is the "corrected yield" of the plat. These corrected yields are comparable for all the plats. In them the variations in productive power of the soil of the various plats are eliminated, in so far as this is possible.

RELATIVE EFFECT OF SUCCESSIVE UNITS OF FERTILIZER.

It is well known that a second unit of a given fertilizer does not produce as great an increase as the first unit, a third unit produces less increase than the second, and so on. German investigators, especially Mitscherlich,[3] have shown that there is much evidence to substantiate the assumption that the ratio between the increases due to any two consecutive units tends to be constant (that is, that the curve of increase is logarithmic). German writers refer to the law governing this rate of increase as the Law of the Minimum, tho the theory of the minimum factor really has nothing to do with the law. This phase of the subject is too complex to discuss in the space here available.

The accompanying brief table illustrates the case in point. The second column shows the increases in yields of cotton at the various experimental farms of the North Carolina station, from the amounts of fertilizers in the first column. The third column shows the increases in yield calculated on the assumption that the ratio between successive increases is constant. With the exception of the second line the results agree very well with the experimental data.

Fertilizer, lbs.	Increase, Actual	Bales, Calculated.	Error.
200	0.205	0.205	0.
400	.400	.364	.036
600	.480	.488	.008
800	.585	.585	0.
1000	.660	.660	0.

Mitscherlich (l.c.) gives several other illustrations of this point.

CALCULATING YIELDS.

If C represent the constant ratio of successive increases in yield due to additional units of a fertilizer, and if I_1, I_2, I_3, etc., represent respectively the increases due to the first, second, third, etc., units, then

$$I_1 = I_1;\ I_2 = CI_1;\ I_3 = CI_2 = C^2I_1;\ I_4 = CI_3 = C^3I_1;\ \ldots \quad I_n = C^{n-1}I_1. \tag{1}$$

If S represent the total increase due to n units of fertilizer, then, by adding the above equations together, we get

$$S = I_1 + CI_1 + C^2I_1 + \ldots + C^{n-1}I_1 = (1 - C^n)I_1/(1 - C). \tag{2}$$

In this equation n is the number of fertilizer units used. The equation

[3] Die Landwirtschaftlicken Versuchs-stationen, 1912, p. 413 et seq.

applies for both whole and fractional values of n. When the increase for a single unit and the value of the ratio C are accurately known, equation 2 serves to calculate the increase to be expected from any quantity of the fertilizer in question, of course within the limits of normal increase due to fertilizer.

To find the quantity of fertilizer giving the greatest profit, all that is necessary is to substitute for I_n in equation 1 above the cost of a unit of fertilizer and to express I_1 in dollars and cents. The work is simpler when the equation is transformed as follows:

$$C^{n-1} = I_n / I_1.$$

Taking the logarithm of both members, we have

$$(n - 1) \log C = \log I_n - \log I_1,$$

from which

$$n = 1 + (\log I_n - \log I_1) / \log C. \tag{3}$$

With accurate values for the various quantities used in equations 2 and 3, the results obtained from such a series of experiments as Series I of this paper would enable us to determine the results to be expected from quantities of fertilizers other than those actually used in the experiments, as well as the maximum profitable quantity in any given case.

Space will not permit me to show, what is actually the fact, that these simple equations, usable by anyone familiar with the use of logarithms, can easily be deduced from the much more complex and vastly more difficult equations of Mitscherlich, and vice versa.

Series I of this paper gives nine values of C for each element, three values for each combination of two elements, and one value for the three elements used together. Series II gives three values for each element, and Series III one value. The average of the nine values from Series I, and even of the three values from Series II, should give a result usable in calculations.

SERIES I.

Fertilizers applied.

Plat No.	Units N P K
1	0 0 0
2	0 0 1
3	0 0 2
4	0 0 0
5	0 1 0
6	0 1 1
7	0 1 2
8	0 0 0
9	0 2 0
10	0 2 1
11	0 2 2
12	0 0 0
13	1 0 0
14	1 0 1
15	1 0 2
16	0 0 0
17	1 1 0
18	1 1 1
19	1 1 2
20	0 0 0
21	1 2 0
22	1 2 1
23	1 2 2
24	0 0 0
25	2 0 0
26	2 0 1
27	2 0 2
28	0 0 0
29	2 1 0
30	2 1 1
31	2 1 2
32	0 0 0
33	2 2 0
34	2 2 1
35	2 2 2
36	0 0 0

Direct comparisons possible in this series.

Nitrogen. Plat No.	Units N P K	Phosphorus. Plat No.	Units N P K	Potash. Plat No.	Units N P K
1	0 0 0	1	0 0 0	1	0 0 0
13	1 0 0	5	0 1 0	2	0 0 1
25	2 0 0	9	0 2 0	3	0 0 2
2	0 0 1	2	0 0 1	5	0 1 0
14	1 0 1	6	0 1 1	6	0 1 1
26	2 0 1	10	0 2 1	7	0 1 2
3	0 0 2	3	0 0 2	9	0 2 0
15	1 0 2	7	0 1 2	10	0 2 1
27	2 0 2	11	0 2 2	11	0 2 2
5	0 1 0	13	1 0 0	13	1 0 0
17	1 1 0	17	1 1 0	14	1 0 1
29	2 1 0	21	1 2 0	15	1 0 2
6	0 1 1	14	1 0 1	17	1 1 0
18	1 1 1	18	1 1 1	18	1 1 1
30	2 1 1	22	1 2 1	19	1 1 2
7	0 1 2	15	1 0 2	21	1 2 0
19	1 1 2	19	1 1 2	22	1 2 1
31	2 1 2	23	1 2 2	23	1 2 2
9	0 2 0	25	2 0 0	25	2 0 0
22	1 2 0	29	2 1 0	26	2 0 1
33	2 2 0	33	2 2 0	27	2 0 2
10	0 2 1	26	2 0 1	29	2 1 0
22	1 2 1	30	2 1 1	30	2 1 1
34	2 2 1	34	2 2 1	31	2 1 2
11	0 2 2	27	2 0 2	33	2 2 0
23	1 2 2	31	2 1 2	34	2 2 1
35	2 2 2	35	2 2 2	35	2 2 2

N and P.

Plat No.	Units N P K
1	0 0 0
17	1 1 0
33	2 2 0
2	0 0 1
18	1 1 1
34	2 2 1
3	0 0 2
19	1 1 2
35	2 2 2

N and K.

Plat No.	Units N P K
1	0 0 0
14	1 0 1
27	2 0 2
5	0 1 0
18	1 1 1
31	2 1 2
9	0 2 0
22	1 2 1
35	2 2 2

P and K.

Plat No.	Units N P K
1	0 0 0
6	0 1 1
11	0 2 2
13	1 0 0
18	1 1 1
23	1 2 2
25	2 0 0
30	2 1 1
35	2 2 2

N, P and K.

No.	Units.
1	0 0 0
18	1 1 1
35	2 2 2

Series II

Fertilizers applied.		Direct comparisons possible in this series.									
		Nitrogen.		Phosphorus.		Potash.		N and P.		P and K.	
Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K
1	0 0 0	1	0 0 0	1	0 0 0	1	0 0 0	1	0 0 0	1	0 0 0
2	0 0 1	10	1 0 0	3	0 1 0	2	0 0 1	11	1 1 0	4	0 1 1
3	0 1 0	3	0 1 0	6	0 2 0	3	0 1 0	18	2 2 0	8	0 2 2
4	0 1 1	11	1 1 0	2	0 0 1	4	0 1 1	2	0 0 1	10	1 0 0
5	0 0 0	4	0 1 1	4	0 1 1	6	0 2 0	12	1 1 1	12	1 1 1
6	0 2 0	12	1 1 1	7	0 2 1	7	0 2 1	19	2 2 1	16	1 2 2
7	0 2 1	6	0 2 0	10	1 0 0	8	0 2 2				
8	0 2 2	14	1 2 1	11	1 1 0	11	1 1 0	N and K.		N, P and K	
9	0 0 0	18	2 2 0	14	1 2 0	12	1 1 1	3	0 1 0	1	0 0 0
10	1 0 0	7	0 2 1	12	1 1 1	14	1 2 0	12	1 1 1	12	1 1 1
11	1 1 0	15	1 2 1	15	1 2 1	15	1 2 1	6	0 2 0	20	2 2 2
12	1 1 1	19	2 2 1			16	1 2 2	15	1 2 1		
13	0 0 0	8	0 2 2			18	2 2 0	20	2 2 2		
14	1 2 0	16	1 2 2			19	2 2 1				
15	1 2 1	20	2 2 2			20	2 2 2				
16	1 2 2										
17	0 0 0										
18	2 2 0										
19	2 2 1										
20	2 2 2										
21	0 0 0										

Series III.

Fertilizers applied.		Comparisons possible in this series.					
		Nitrogen.		Phosphorus.		Potash.	
Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K	Plat No.	Units N P K
1	0 0 0	5	0 2 2	1	0 0 0	3	0 2 0
2	0 1 0	6	1 2 2	2	0 1 0	4	0 2 1
3	0 2 0	7	2 2 2	3	0 2 0	5	0 2 2
4	0 2 1						
5	0 2 2						
6	1 2 2						
7	2 2 2						

THE INTERPRETATION OF WATER-REQUIREMENT DATA.[1]

R. S. VAILE.[2]

Some years ago the Utah Agricultural Experiment Station set forth the principle that the proper unit for measuring the crop-producing power of irrigation water is the crop produced per acre-inch of water rather than that produced per acre of land. Considerable data have been submitted by various Utah workers in which this unit is supposedly used in determining water requirements and duty of water.[3] The present writer feels that many of these data have been presented with an emphasis that leads to erroneous, or at best only partially correct, deductions and conclusions. Judging from the general form of the publications above referred to, they are designed primarily for the practical farmer and are expected to point the way to actual field practice. For this reason, particularly, the present writer feels that the data should be rearranged or the arrangement enlarged to include a factor that so far has been largely overlooked.

The general statement that the acre-inch is the proper unit to use in measuring the crop-producing power of water is readily accepted, and its important bearing on farming operations should be urged on all irrigation farmers. In the determination of the yield per acre-inch of water applied, however, the starting point must be the expected dry-farm yield for the same crop on the same land. Only the increase in production above the usual unirrigated yield may be properly credited to the irrigation water. It is obvious that only in special cases will this point be zero. The Utah publications have used zero as a starting point in nearly all cases, or if they have considered the dry-farm value, it has not been given proper weight in their tables and conclusions. Fortunately, the published data give opportunity, in nearly every case, for a rearrangement on the basis of increase over dry-farm yields brought about by irrigation.

The present writer desires to submit the following proposition: "In figuring the comparative crop-producing power of a definite amount

[1] Paper No. 73, University of California, Graduate School of Tropical Agriculture and Citrus Experiment Station, Riverside, Cal. Received for publication December 13, 1920.

[2] Assistant professor of orchard management.

[3] Note particularly Utah Agricultural Experiment Station Bulletin 115, 116, 117, 118, 119, 146, and 157.

of irrigation water when used on various units of land, the same total area of land must always be considered and the dry-farm yield credited to any portion not irrigated by reason of increased application to other portions." In other words, if the crop-producing power of 30 acre-inches of water is being considered when all applied to 1 acre as compared to an application of 5 acre-inches to each of 6 acres, then it is only fair in the former case to credit the total yield with the expected yield of 5 acres dry farmed. To illustrate, if 30 acre-inches of irrigation water are distributed 5 inches deep over 6 acres and result in a yield of 60 bushels per acre, the total result for irrigation, as expressed by the Utah writers, would be 360 bushels. If, on the other hand, the 30 acre-inches were all used on one acre and the yield should be 150 bushels for that 1 acre, then the Utah writers would form a comparison between 360 and 150 and conclude that it would be better irrigation economy to use the water distributed on all the land. Suppose, however, that this same land is capable of producing 50 bushels per acre without irrigation, 5 acres would then produce 250 bushels. This added to the 150 bushels produced on the 1 acre irrigated with the 30 acre-inches gives a total yield from the 6 acres of 400 bushels, or an increase of 40 bushels over the method of broader distribution of the water. This, the present writer believes, is the fairer basis of comparison. In applying the above method of comparing results to the data submitted in the Utah reports, several suggested conclusions are modified, at least in detail. The following typical examples are submitted:

1. The crop-producing power of 30 acre-inches when applied to different areas of land cropped to corn is shown in Bulletin 117, Table 10, to be 97.12 bushels when applied to 1 acre, 187.86 bushels when spread over 2 acres, 268.56 bushels on 3 acres, and 316.56 bushels on 4 acres.

But the dry-farm yield has been forgotten! On page 85 it is stated to be 43.76 bushels per acre. Allowing for this yield on a sufficient area to complete the 4 acres of land cropped in each case, the figures just cited are converted into the following:

1 acre irrigated,	3 acres dry farmed,	total yield,	228.40 bushels.
2 acres irrigated,	2 acres dry farmed,	total yield,	275.40 bushels.
3 acres irrigated,	1 acre dry farmed,	total yield,	312.32 bushels.
4 acres irrigated,		total yield,	316.56 bushels.

In this case the conclusion that the 30 acre-inches may most economically be distributed over 4 acres is possibly still tenable, altho the margin of difference is very small and might not be sufficient to war-

rant the extra expense involved in the irrigation of the larger area. The arrangement of the data as originally submitted, on the other hand, seemed to indicate an unquestioned superiority in favor of the distribution over the entire area.

2. In Bulletin 116, Table 5, the following figures occur:

Percentage of crop weight due to rain and soil water as compared to 7.5 acre-inches of irrigation water: Wheat, 86 percent; corn, 80 percent; potatoes, 67 percent. Using these figures with the data presented in Table 6 for the yield with 7.5 acre-inches of irrigation, the following expected dry-farm yields of dry matter are obtained: Wheat, 4,888 pounds; corn, 8,615 pounds; and potatoes, 1,829 pounds.

If units of 50 acre-inches of water and 10 acres of land are used,

TABLE I.—*Results obtained from 50 acre-inches of irrigation water used in varying amounts on all or part of 10 acres of wheat, corn and potatoes, with the balance of the 10 acres dry farmed in each case.*

Acres irrigated.	Acres dry farmed.	Water per acre.	Yield of dry matter per acre. Irrigated.	Yield of dry matter per acre. Dry farmed.	Total yield of dry matter.	Yield of dry matter per acre-inch. Irrigation water.[a]	Yield of dry matter per acre-inch. Total water.[b]	Yield of dry matter per acre-inch as given in Table 6. Irrigation water.	Yield of dry matter per acre-inch as given in Table 6. Total water.
		Inches.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
				WHEAT.					
0	10	0	....	4,888	48,880	....	355	....	355
10	0	5	4,969	4,888	49,690	994	265	994	265
5	5	10	5,684	4,888	52,860	1,057	282	568	239
2	8	25	6,672	4,888	52,448	1,049	279	267	172
1	9	50	7,999	4,888	51,991	1,039	277	160	125
				CORN.					
0	10	0	....	8,615	86,150	....	1,555	....	1,555
......	......	5	....	....	....	....	....	....	....
5	5	10	12,672	8,615	106,885	2,137	1,014	1,276	821
2	8	25	14,606	8,615	98,132	1,963	931	584	478
1	9	50	12,637	8,615	90,172	1,803	854	230	209
				POTATOES.					
0	10	0	....	1,829	18,290	....	296	....	296
10	0	5	2,310	....	23,100	462	207	462	207
5	5	10	2,925	1,829	23,760	475	212	293	181
2-1/2	7-1/2	20	4,005	1,829	23,729	474	212	200	153
1-1/9	8-8/9	45	3,795	1,829	20,475	409	183	84	74

[a] Based on the use of 50 acre-inches in all cases.

[b] Based on 50 acre-inches irrigation, plus ten times the rain and soil moisture as given for 1 acre (13.74 inches) in all cases.

then the following tables a submitted above and those found in Table 6 (Utah Bulletin 110). The choice of these particular units is, of course, entirely arbitrary, except that the proportion between acre-inches and acres of land is such that the entire tract will just be covered by the smallest irrigation application used in the experiments.

The striking thing brought out by the above figures is the difference in ratio between the amounts of dry matter produced by a given amount of irrigation water when used in various ways, as determined by the two methods of comparison. This difference depends upon whether the unit of land used for the total yield is kept constant by including the dry-farm yield on the unirrigated portions, or whether the unit of land cropped is changed to correspond only to the amount covered with irrigation water. It seems to the present writer that the latter method (which is the one used by the Utah authors) is open to criticism in that it introduces so obvious a variable in the extent and value of the original plant as well as in the labor outlay. It is even further at fault in that it does not give sufficient weight to the rain and soil moisture, for in the case of the distribution of the irrigation water over the 10 acres the amount of water furnished by nature is not limited to 13.74 acre-inches (the figure used in case of wheat), but becomes ten times that amount.

3. In Bulletin 146 of the Utah station the following statement occurs: "The total yield (produced by natural soil moisture and 20 inches of irrigation water) was more than three times as much when the 20 acre-inches were used on 4 acres as where the water was all applied to 1 acre" (p. 25). The obvious implication would seem to be that it were decidedly better irrigation economy to spread the 20 acre-inches over the 4 acres. However, in case all the water is used on 1 acre, the other 3 acres are forgotten in arriving at this conclusion, altho the complete data of yields as listed on page 30 show a considerable dry-farm possibility for them. Utilizing the data presented on page 30, Table 2 has been compiled.

From Table 2 it becomes evident that the distribution of the 20 acre-inches over the 4 acres is very little better than the use of the entire amount on 1 acre, with the other 3 acres dry farmed. In fact, the difference indicated is not greater than the experimental error that is to be expected in such field trials. In this case, the conclusion stated by the authors of the bulletin, namely, that the best practice seems to be to irrigate with 15 acre-inches divided into three applications, still holds. In the next example the soundness of the authors' deductions does not seem so clear.

TA[illegible] 2.—*Yields of wh[illegible] [illegible] acre-inches of irrigation water used in varying amounts on all or part of 4 acres, with the bala[illegible] [illegible] [illegible]med.*

Acres.		Water used per acre.	No of applications.	Yield per acre.		Total yield on 4 acres.
Irrigated.	Dry farmed.			Irrigated.	Dry farmed.	
		Inches.		*Bushels.*	*Bushels.*	*Bushels.*
0	4	0	0		37.3	149.2
$1\frac{1}{3}$	$2\frac{2}{3}$	15	3	52.4	37.3	199.4
2	2	10	2	45.1	37.3	164.8
4	0	5	1	40.8	—	163.2
1	3	20	4	45.7	37.3	157.6

4. In the summary of Bulletin 157, item 4 states "one inch weekly, or a total of 12.8 inches during the season, gave a higher yield than any other treatment." The author has evidently forgotten for the moment his oft-repeated slogan that the unit of measure for irrigation economy should be the acre-inch of water rather than the acre of land. For the purpose of compiling a comparative table from the data submitted in the above bulletin, the present writer has taken the arbitrary units of 45 acre-inches of irrigation water to be used on all or any part of 9 acres of land planted to potatoes. (The reason for using this proportion between land and water is again found in the fact that it just accommodates the smallest quantity of water used in the experiments, when distributed over the entire area.) The data in Table 3 result.

TABLE 3.—*Yields of potatoes obtained from 45 acre-inches of irrigation water used in varying amounts on all or part of 9 acres.*

Number of acres.		Total water used per acre.	Stage at which applied.	Yield per acre.		Total yield on 9 acres.
Irrigated.	Dry farmed.			Irrigated.	Dry farmed.	
		Inches.		*Bushels.*	*Bushels.*	*Bushels.*
0	9	0			153.3	1,379.7
9	0	5.0	3.	229.0		2,061.0
3.5	5.5	12.8	1 inch weekly	337.1	153.3	2,032.0
4.5	4.5	10.0	3, 4.	255.4	153.3	1,838.1
2.25	6.75	20.0	1, 2, 3, 4.	317.3	153.3	1,748.6
3	6	15.0	1, 3, 4.	257.2	153.3	1,691.4

The present writer does not have in mind a complete discussion of the economics of irrigation agriculture in this paper; there are certain definite principles and many variable factors that can not even be mentioned. It is generally held that the margin of financial profit increases with the increase in yield per acre, only up to some fixed point;

it is commonly recognized that dry-farm crops have a greater value than the same weight or bulk of irrigated crops because of superior quality; there is a vary [illegible] of irrigation water, dependent in part [illegible] of water is distributed over a limited or extended area; in certain cases the dry-farm yield can not be produced at a financially profitable figure; all these and many other considerations must be in the farmer's mind before he determines just what system will give the greatest economy in water usage on his particular farm. The present writer feels, however, that the method of figuring water duty suggested above has much to commend it to the practical operator and is less likely to be misleading than the method used in the publications reviewed.

All of the above tabulations or illustrations are designed to show the reasonableness of the proposition stated at the beginning. For sake of clearness, let us restate it in conclusion: "Given a farm of definite area and a definite amount of available irrigation water; given, further, the possibility of producing profitable crops under a system of dry farming; then, in case the irrigated area is decreased by increasing the acre application of a part of the farm, it is not fair to assume that the total area cropped will be reduced, but rather that the land released from irrigation will still maintain its dry-farming value." There is nothing in this proposition that in any way interferes with the principle that the acre-inch of water should be used as a unit in measuring water economy, but it merely suggests a method of utilizing that unit fairly.

COMMENT ON R. S. VAILE'S DISCUSSION OF UTAH RESULTS.

F. S. HARRIS.[1]

In his discussion of irrigation experiments at Utah, Professor Vaile lays much emphasis on the need of giving proper consideration to the crop-producing power of the natural precipitation independent of the irrigation water applied. He shows a method of arranging the irrigation data in a way that will help the user of water to decide how much to apply as a supplement to dry farming. His method of arranging the material is interesting just as any additional way of presenting facts brings out interesting relations. Many such ways of arranging our material have presented themselves to us, but have not

[1] Formerly director, Utah Agricultural Experimental Station, Logan, Utah.

been used because of their lir' ' 'd applicatio' ' ' ' felt ' ' th wished could v ' '

I am sorry that Professor V' '' irrigation philosophy of either Dr. Widtsoe or myself, as his paper indicates that he is. For example, in discussing Utah Station Bulletin 147, he says that the obvious implication would seem to be that it were decidedly better irrigation economy to spread 20 acre-inches over 4 acres." I fail to see how he reached this conclusion when the summary of the work states clearly that "these experiments show rather conclusively that on the deep soils of Utah the best system of irrigating wheat is to apply three irrigations of about 5 inches each."

Of course, the efficiency of each inch of water is greater with the lower applications of water, but other factors, such as labor, cost of land, and many other items, must be taken into consideration in deciding on the practice that is best to follow. There is nothing sacred about either the water or the land except as they contribute to the welfare of man; hence the efficiency of either the acre-inch of water or the acre of land is not the ultimate end to be sought. The real aim should be to use the land and water together in such a way that man will be best served. Where water is the chief limiting factor, it should be given first consideration; where land is scarce, its efficiency needs special attention.

We have used as a basis of all our irrigation studies the idea that irrigation water should be used as supplementary to the natural precipitation, or as Dr. Widtsoe has stated it, "The beginning of irrigation wisdom is the conservation of the natural precipitation." In most of our publications we have stated as nearly as we could what percentage of the crop came from the precipitation and what from the irrigation.

Probably the chief limitation in Professor Vaile's method of computation comes from the fact that in most places where irrigation is practiced no profitable crop can be raised at all with the rainfall unless it is supplemented by irrigation water; hence it is impossible to consider any dry-farm crop on the unirrigated acres and no accurate calculations can be made with this as a basis. This is the main reason why we have not made this computation, even tho on our Greenville farm there is sufficient rainfall to mature dry-farm crops. Over much of the State economical crops can not be produced without irrigation.

VARIETAL NOMENCLATURE OF OATS AND WHEAT.[1]

George Stewart.[2]

Varietal nomenclature of the small cereals is far from satisfactory. This is due in part to the fact that commercial varieties have been introduced with the same names that were used to designate them while they were still on test at some experimental farm. This is good practice when the names are desirable, but such is not always the case. Importations from foreign countries have occasionally brought their native names with them. Some of these names are long and have no particular suggestiveness in America, tho they may have had in France, Russia, Algeria, or Turkestan. Many foreign words are difficult for English-speaking people to pronounce and are more than ordinarily hard to spell. At home, names of imaginary or extravagant qualities have at times been added for one reason or another. Finally, the name of some man or experiment station, whether worthily or unworthily does not matter, has become attached to several varieties of widely different qualities or adaptation. When a number is made part of such a name the trouble is increased.

Two pieces of work have greatly improved conditions with respect to classification, or at least opened the way for such improvement. Dr. W. C. Etheridge,[3] now of the Missouri station, while a graduate student at Cornell University made a careful study of oat varieties. He worked with a collection of about 600 varieties that Prof. E. G. Montgomery had gathered in America and Europe. Less than 60 of these were found to be actual botanic varieties, the others all being duplicates of one or another of the accepted forms. A wheat varietal study of even larger proportion is now being conducted by Clark, Martin, and Ball,[4] of the Office of Cereal Investigations, United States Department of Agriculture.

Both of these studies are classic in the fields they represent, the classification of varieties of oats and wheat. Suitable names are of

[1] Contribution from the Department of Field Crops, Utah Agricultural Experiment Station, Logan, Utah. Received for publication October 20, 1920.

[2] Professor of agronomy, Utah Agricultural College.

[3] Etheridge, W. C. A classification of the varieties of cultivated oats. N. Y. Cornell Agr. Expt. Sta. Memoir 10, 1916.

[4] Clark, J. A., Martin, J. H., and Ball, C. R. Preliminary classification of American wheat varieties. *In manuscript.*

secondary, tho not of negligible, importance. From this standpoint neither piece of work is all that could be desired, in spite of the fact that each has appreciably improved the varietal nomenclature of the crop studied. It would be too much to expect such large fields to be cleared in one stroke.

Etheridge chose the name for his variety by a sort of ballot system—that is, he kept count of the number of times a given variety was observed to bear a given name and gave to the variety the name applied to it the greatest number of times. Probably a more impartial method could not have been found, but it gave a troublesome or an unwieldy name an equal opportunity with a desirable one.

In the wheat classification study an effort is being made to get back to the original, or rather to the rightful, name of a variety from the standpoint of historic justice. This method seems to have more to recommend it than does the method used for oats. It should be emphasized that both methods are superior to the one to be herein suggested, if there is anything peculiarly sacred about a name in and of itself.

In this article any such intrinsic value is ignored when the original name is particularly objectionable for some reason. In other words, the author contends that unwieldy, troublesome, or extravagant varietal names should be replaced by simple ones, if at all in keeping with the popularity or historic justice of any given name. Frequently the original name can be modified in such a manner as to make it simple and safe. At any rate, new varieties should not be encumbered needlessly.

Numbers are necessary in experimental work to designate strains, but not for commercial varieties, where they offer chances for error. The fact that one variety of wheat is known in New York as Fortyfold, No. 6, International No. 6, Rochester No. 6, Genesee No. 6, Michigan No. 6, Clawson No. 6, Jones No. 6, and No. 16 shows the meaninglessness of numbers. There is no way of telling from the name alone that Jones No. 6 is an absolute synonym of Genesee No. 6 or of Fortyfold. The names No. 6 and No. 16 would be accepted as the names of separate varieties. The name part of the varietal designation is much more significant than the figures and leads a person to believe different varieties are indicated by the names Clawson No. 6 and Jones No. 6, for example. Should some seedsman drop off the number, the confusion would then be complete. The use of numbers of any kind for trade names affords opportunity for entanglement, and hence for error. The author, therefore, favors the abandonment of all numbers from the nomenclature of commercial varieties.

Troublesome as numbers ordinarily are, they have infinitely more possibilities for mischief when they are so similar that a slip of the pencil or of the typewriter would change one into the other. Especially unfortunate in this respect are two varietal names of oats, Garton No. 748 and Garton No. 784. The only difference in the names is the interchange of the 8 and the 4. Warburton holds the opinion that this is the way in which No. 748 came into existence, No. 784 having been the original designation. In 1917 the author reported some work on classification of oat varieties that he had done at Cornell University. In one of the paragraphs the "748" was written "784." This later caused him much trouble. Garton No. 473 and Garton No. 691 are possibly less dangerous, for none of the figures are identical; but should a typist leave off either of the numbers trouble would follow, as the term "Garton" could not serve to identify the variety if it is used as part of more than one varietal name.

The C. I. numbers of the oat key further illustrate the danger of numbers. They are as follows: C. I. No. 602, C. I. No. 620, C. I. No. 603, and C. I. No. 606. A glance shows how easily 620 and 602, 602 and 603, or 603 and 606 could be mixed, and consequently muddled.

Besides the numbers used as names, several others are fraught with possibility of error. "Silvermine" and "Silvermine Selection" are used for two distinct varieties. The word "Selection" is attached to several other names. Such combinations of names as Victor and Irish Victor, Golden Giant and Golden Drop, Green Russian and Green Mountain, Storm King, Tartar King, and White Tartar deserve consideration. Compare with them a few of the simpler names, such as Lincoln, Belyak, Silvermine, Joannette, Culberson, and Burt. Simple one-word names are especially distinctive. Double names, such as Swedish Select, Red Rustproof, Danish Island, and Green Mountain, are probably satisfactory, but have no advantage over the single-word names. Because the words Tobolsk and Probsteier do not end in English syllables both are difficult to pronounce and hard to spell. Tho strange, Belyak and Mesdag are easy to spell, because the syllables are in pronounceable English. None of the last four names, however, is suggestive in English.

Finally, "Garton" is repeated several times in widely separated parts of the key, usually with a number added. Let a typographical error occur in which the number is lost or mixed, and identity has disappeared completely.

The Washington Agricultural Experiment Station has continued

many of its pedigree, or line, numbers as varietal names of wheat when later introduced commercially. Some of these are: Washington 3, Washington 60, Washington Hybrid 63, Washington Hybrid 123, Washington Hybrid 128, and Washington Hybrid 143. All the objections to numbers mentioned in the discussion of varietal names for oats apply here. Numbers such as 3 and 63, 123 and 128, 123 and 143, or 60 and 63 are combinations that render confusion easy, even by the slightest typographical error. Since the word "Washington" is attached to six distinct varieties, this part of the name the part that should be distinctive, means next to nothing. In two of the names the number is added directly to the word "Washington," whereas in four others the word "hybrid" intervenes. This complicates matters by making the names so long as to be unwieldy.

Some other numbers that look as if they could easily cause trouble are Rural New Yorker No. 6 and Rural New Yorker No. 57. Nebraska Hybrid 28 might easily be confused with Washington Hybrid 128. The number part of Buffum No. 17 adds nothing to the significance of the name, since "Buffum" appears just this once in the entire key of wheat varieties. There also seems to be no necessity for two names like Jones Longberry No. 1 and Silversheaf Longberry. One might just as well be merely Longberry and the other Silversheaf. Note the cumbersome length of Jones Longberry No. 1 and Rural New Yorker No. 57 when compared with shorter names such as Marquis, Prelude, Humpback, Gypsy, and a number of others.

In addition, there are some outright invitations for entanglement in the names themselves. Take, for example, "Ruby" and "Rudy." In this pair the exchange of a "b" and a "d" causes a complete change of variety, correctly spelled and to all appearances a correct name. "Humpback" and "Humpback II" offer similar facilities for loss of identity. In some cases repetition of part of the name is frequent, as in Martin Amber, Mammoth Amber, and Imperial Amber. The same is true of White Fife, White Track, and White Winter. In addition, the last two names might be equally significant when applied to a number of other varieties.

A few oddities have also survived in the key, such as Kota, Norka, and Oatka. Somehow these have missed accomplishing what Kanred and Dicklow do so admirably. Then K. B. No. 2 and D 5 are peculiarly ineffective as names. Here the dangers from numbers and from non-suggestive names are combined.

The Canadian names, Marquis and Prelude, show up well as examples of simple names when compared to Washington Hybrid 128,

Fultzo-Mediterranean [illegible] to say nothing of Silversheaf Longberry.

Some more names too long or too awkward to be satisfactory are Regenerated Defiance, Diehl-Mediterranean, Jones Winter Fife, English Squarehead, and Squarehead Master. The same is true, only in a somewhat lesser degree, of such names as Colorado Special, California Gem, Wyandotte Red, Early Red Clawson, and Sommerweizen. Compare these for brevity with Bobs, Dicklow, Turkey, Kanred, Fultz, Huston, Poole, Glyndon, Wellman, Ruby, Kofod, Sevier, Indian, Sonora, Gypsy, and a host of others. The shorter names are more effective and lack the constant nightmare of misspelling that is almost sure to haunt the path of such names as Marouani, Sommerweizen, Diehl-Mediterranean, and even of Coppei and Washaho.

CONCLUSIONS.

All numbers when used as part of the name of a commercial variety are bunglesome; some combinations are dangerous so far as accuracy is concerned, since only the slightest slip of pen or typewriter is necessary to cause a complete loss of identity. It seems the better part of wisdom, therefore, to discard any numbers from the name of a commercial variety, notwithstanding the indispensability of numbers for experimental work.

Where possible, long names should be avoided either by using one part of the name or by compounding a part of one of the name words with a part of the other, as in Kanred, Minhardi, and Dicklow. Care is, of course, necessary, or ridiculous names may result. In a few cases it might be better completely to discard a long name, at least a much-compounded one, and to re-christen the variety with a short one-word name.

SUGGESTIONS.

Montgomery[5] has suggested that a registry book be started for crop varieties. In this book would be recorded a description, a statement of the adaptation, and as much history of a variety as is available. When a new introduction is to be made, its description and history would be recorded. Specimen types might also be kept in a herbarium of some sort to assist later workers to identify with certainty the varieties with which they are working. After a few years such a book and herbarium would begin to acquire historic as well as practical value. This work would most likely be assigned to the State or National department of agriculture.

[5] Montgomery, E. G. On naming varieties. *In* Jour. Amer. Soc. Agron., v. 7, p. 29–31. 1915.

A [illegible] ganization such as [illegible] herd-books might be advi[illegible] [illegible] change if deemed best, of new names might be left to some officer or committee in the organization. Names are not scarce. Some [illegible] ones [illegible] for oats are President, Wideawake, Prosperity, Abundance, National, Sensation, Welcome, and Roosevelt. For wheat a list of simple names has already been given. At any rate, the experimental number would not be part of the commercial name.

THE TEACHING OF SOIL BACTERIOLOGY.[1]

PERCY EDGAR BROWN.[2]

Soil bacteriology as a science is of comparatively recent development. Its newness is evidenced by the way in which the subject is taught, but more particularly by the fact that it is not included at all as a separate course in many of our agricultural college curricula.

With the accumulation of information regarding the bacteriology of the soil, however, resulting from the extensive investigations along this line in recent years, the importance of the subject is becoming more and more widely recognized and most institutions are now awakening to a realization of the fact that the study of soils is almost as incomplete without bacteriology as it would be without chemistry. Indeed, it is quite generally conceded that three factors, the chemical, the physical, and the bacteriological, control the fertility or crop-producing power of soils, and that these factors are of about equal significance.

The teaching of soil bacteriology is therefore a subject of much interest and importance at the present time. The purpose of this paper is to call attention to the need for special courses in this science and to discuss the place which such courses should occupy in the curriculum and the ways in which the subject matter may be presented.

Soil bacteriology is an applied science, an application of bacteriology to soil science, and thus to agricultural science. Hence the teaching of the subject will be considered only in connection with agricultural courses. General bacteriological courses should undoubtedly include some reference to the relation of bacteria to soils, but obviously mere

[1] Paper presented at the meeting of the Society of American Bacteriologist's held in Chicago, Ill., on December 29, 1920. Contribution from Iowa State College, Ames, Iowa. Received for publication January 10, 1921.

[2] Professor of soil bacteriology, Iowa State College.

fundamentals can be presented in this way. Such a bird's-eye view, as it were, of the subject is probably sufficient for general science students. In agricultural courses a more comprehensive study of the part which bacteria play in maintaining soil fertility is quite necessary if the student is to acquire a proper viewpoint of farming practices and any adequate conception of the essentials of successful crop production.

Soil bacteriology has a place, therefore, in the curriculum of every agricultural college in connection with other soils courses. Furthermore, it is of so much importance that it should be given as a separate course and not, as is so often the case, considered only in a brief way in connection with a general course in soils or in soil fertility.

It has been well said that the whole business of agriculture is founded upon the soil, and the presentation of the science of soils in more than one course is now more than a matter of expediency. It is absolutely necessary if the student is to secure a thoro understanding of the subject. It is not in place to consider here what these various soils courses should be called, nor what they should include, except in so far as they affect the teaching of soil bacteriology. Suffice it to say that experience along this line at the Iowa State College indicates that a general course in soils should be followed by a course in soil fertility, this in turn by soil bacteriology, and the final course, involving a practical application of the other three, should be soil management. This arrangement of courses shows quite clearly the importance attached to soil bacteriology, and it also indicates the desirable prerequisite soil courses. According to this plan soil fertility is a prerequisite for soil bacteriology and soil fertility requires the completion of the general course in soils, hence both these courses must precede soil bacteriology. But other general science courses are also necessary and the student is required to complete a course in general bacteriology and two years' work in chemistry before taking up soil bacteriology. In fact, the chemical courses are prerequisites to soil fertility. Thus upon the foundation of chemistry, bacteriology, and soils there is erected the superstructure of soil fertility, soil bacteriology, and finally soil management. With the omission of any one of these parts, the structure would be incomplete. With soil bacteriology left out, soil management would become a collection of uncomprehended data, of uncorrelated facts, and of unexplained recommendations. In short, soil bacteriology is the key which provides the solution of many of the mysteries of crop growth in relation to soil conditions, those mysteries which have for centuries puzzled the farmer and evaded explanation by the scientist.

The importance of teaching soil bacteriology in connection with other soils courses seems quite evident and the prerequisites which the course should carry should undoubtedly include chemistry, bacteriology, and soils. The next question which arises pertains to the method by which the subject should be taught.

In all teaching there seems to be a wide diversity of ideas regarding the proper methods to be followed. Some pedagogical experts present lengthy arguments in favor of certain methods of procedure, while others have quite as extensive support for an entirely opposite position. It is probably true that teaching methods, at least of science subjects, should be adapted to the particular science, and it seems rather unreasonable to expect the same methods to prove adapted to the wide variety of science subjects which are now included in our college and university curricula.

With all due respect to our good friends, the pedagogs, it appears that specialists in particular branches of science are really much better qualified to select the best method of presenting their subjects to college students than are educational experts who may have no clear conception of the subject matter to be presented, and certainly can not have any extensive insight into a wide range of science subjects, such as would be necessary if they were to adapt their teaching ideas to various sciences.

In new sciences it is particularly difficult to determine the method of teaching and what should be taught. In older sciences there are many textbooks and laboratory guides embodying the results of the teaching experience of many specialists. From among the various methods suggested each teacher may choose that particular one which seems more nearly to be adapted to his conditions and most closely to meet his requirements.

In soil bacteriology there are no textbooks which are adapted to special courses in the subject. It is true that many bacteriologies contain excellent sections on the subject and a few soil texts consider at some length the relation of bacteria to soil fertility. In no case, however, is the material presented with sufficient completeness or prepared in a satisfactory way to meet the requirements of a separate course in soil bacteriology. Some day many texts on the subject will undoubtedly be available, but it is probably just as well that this is not true now, for many of our ideas along soil bacteriological lines are undergoing considerable change and the newer phases of the subject are developing very rapidly and are beginning to demand more attention. Rearrangements and many readjustments are therefore constantly re-

quired in subject-matter outlin[illegible] seems hardly ripe for textbooks on soil [illegible]

In the absence of tex[illegible] must be followed or a modified lecture method consisting of a combination of lectures, specially prepared notes, and qui[illegible] Inasmuch [illegible] soil bacteriology is a rather advanced course and can not come early in the college course, the lecture method seems entirely satisfactory. Ten years' experience with this method at Ames has confirmed this conclusion. Furthermore, it has been found also that the subject proves very attractive to students, and no difficulty has been experienced in securing and holding their interest without textbooks or outlines. In fact, it seems that the lack of these usual accompaniments of a study brings about more attention and a greater effort to acquire a full understanding of the subject. Outlines have a tendency to reduce the interest of the student and to cause him to slight the taking of notes, questioning their value. The same result comes from providing full notes on the lectures, and to an even greater extent. Oral and written quizzes are, of course, quite desirable in connection with the lecture work, particularly the former, as opportunity is thus afforded for correcting any misconceptions which may have arisen in the students' minds, and for emphasizing important points, as well as for determining to what extent the students have grasped the subject.

In general science as well as in applied science courses it has been commonly conceded that laboratory instruction in connection with classroom work is very desirable, if not absolutely necessary. There seems no reason to question this conclusion when soil bacteriology is considered. It is, of course, quite possible to teach the subject without laboratory work, just as in the case of other sciences, but "seeing is believing," and the student who really studies the bacteria and their action in the laboratory most certainly receives and retains far more information on the subject. It becomes more of a reality to him, more practical in nature, and not merely a theoretical subject. If at all possible, courses in soil bacteriology should include laboratory work along with classroom instruction.

The material which should be presented in the classroom and in the laboratory is the next question which should receive attention. It is not intended to outline here the course as it is being taught, nor to venture to say how it should be taught, but merely to call attention to some points which are considered very important in connection both with the lecture work and with the laboratory exercises.

In the first place, emphasis should be placed upon the importance of

a p[illegible] ection of the n[illegible] marization of the conclusions wh[illegible] cal considerations should be most carefully differentiated from definite facts. The separation of the wheat from the chaff is a difficult but very essential operation when preparing lecture material in soil bacteriology. Not that there is so much questionable data on the subject, but that so many conclusions are little warranted and some methods of presenting the results of studies along this line are confusing, if not actually misleading. Some phases of bacterial action should be emphasized particularly, as, for example, nitrification and azotofication, while others such as deazotofication are minimized. The relation of bacteria to other elements than nitrogen should be considered at almost as much length as the bearing of the action of these organisms upon the nitrogen problem. Attention should be given to the carbon cycle, to the sulfur cycle, to the phosphorus problem, and so on. Mold action and the occurrence of protozoa and other organisms in the soil should be considered briefly. In short, the more essential phases of the subject should receive major attention, while secondary theoretical problems should be relegated to a minor place in the discussion.

Again, the subject matter should be presented in such a way that the student can "tie it in" with his previous knowledge and correlate it with his agricultural experience. It should not be made too technical or too advanced, but given a practical turn or interpretation which will fix the principles in the student's mind. It is not nearly so essential that he remember the names and the life histories of a lot of soil organisms as it is that he obtain a new conception of the soil as a place where plant food is prepared and where proper bacterial action to a large extent determines crop production. Neither is it as important that he study the intricacies of the chemistry of bacterial action and interactions as it is that the common farm practices appear to him in a new light. Tillage, drainage, manuring, green manuring, liming, and other operations are presented from a new angle and it is by linking up the subject with such every-day practices that it becomes of the most interest and value. Such practical application of the principles involved need in no wise detract from the scientific accuracy of the subject matter, but will merely serve to bring it within range of the student's line of thought and make it of the greatest value to him in his life work.

In connection with the laboratory work, the selection of the proper exercises is a matter of great importance. This selection must be based not only upon subject matter, but also upon adaptation to the student's

previous training and upon the time available for the work. This latter factor is of special importance, as most exercises in soil bacteriology must be handled at definite times, depending upon the necessary incubation period. Unless it is possible for students to work in the laboratory at other than the regular periods, the arrangement of the exercises should be such that the experiments are started at a certain time and the determinations made at a specified period. It is also necessary, of course, that the total amount of work required shall fit in with the time permitted on the student's schedule. For this reason it is very desirable that the laboratory exercises be chosen most carefully. The laboratory manuals on soil bacteriology which are available are all rather complete and it is improbable that all the exercises called for could be handled in one undergraduate course. A selection of the more important ones is therefore essential. It seems that these exercises should at least include the counting of bacteria and molds, the study of ammonification, nitrification, azotofication, deazotofication, and rhizofication. Cellulose fermentation and sulfur oxidation should also be included and the student should study the azotobacter, *B. radicicola,* and a few common soil organisms. With more time other exercises may very well be included, but one exercise along each of these lines will give the student a good fundamental working knowledge of the subject.

As in the case of the lecture work, it is very desirable that the laboratory exercises be given as much of a practical aspect as possible. This may be accomplished by having the student work with certain definite soils and by requiring that at the completion of the course a write-up be prepared which shall contain an interpretation of the data secured. At the Iowa State College the students are urged to secure soil from their own home farms and to study the bacterial factor in those soils. Frequently the same soils are employed which are used in the fertility course and the student secures further knowledge of his own soils. A maximum interest in the laboratory work is secured in this way. If it is not possible for a student to obtain soil from a farm in which he is interested, then he is required to study the soil from an experimental plat, on which definite treatments have been practiced for some years and from which crop yields have been secured. It is usually considered preferable that two soils be studied, selecting those which have been differentiated by treatment and are not at all alike in crop production. By making definite soils the basis of the laboratory work, and by insisting upon a full report and interpretation of the results, the work becomes real soil bacteriology and not

a mere accumulation of bacteriological and chemical exercises, and the students derive the most possible value from the course.

Almost a century ago Liebig declared that "agriculture is of all industrial pursuits the richest in facts and the poorest in their comprehension." Soil bacteriology is facilitating to a wonderful degree the comprehension of agricultural facts and, as investigations progress, the accumulated observations of centuries are being subjected to a new scrutiny. Under the high power objective, as it were, they are analyzed, sorted, classified, and interpreted. The facts which are constantly being brought to light at the present time in agricultural investigations are also being subjected to the same minute examination. While many of them do not at once come into focus and may for some time elude every effort toward interpretation, eventually they will all be explained. Soil bacteriology does more than provide a mere interpretation of observations, however. It leads to the recognition of new facts, it opens new fields of investigation, it permits the establishment of new practices, and it brings about the laying down of new principles. Liebig once said, "Facts are like grains of sand which are moved by the wind, but principles are these same grains cemented into rocks." Soil bacteriology is the cement which binds many agricultural facts into the hard rock of agricultural principles and practices.

In general, changing the simile again, it may be said that when properly understood and applied soil bacteriology is the microscope thru which agricultural science and farming operations appear more clearly and distinctly. With greater magnification or understanding of the subject, the more in detail will the picture of crop production appear.

It is apparent, therefore, that if agricultural students are to receive a proper understanding of soils and crop growth, soil bacteriology must be taught in a special course, the proper material chosen for the course, and the subject tied in with agricultural practices.

THE APPROVED SEED PLAN OF THE MISSOURI CORN GROWERS' ASSOCIATION.[1]

ROY T. KIRKPATRICK.

At the second annual meeting of the International Crop Improvement Association, held in Chicago on December 1, 1920, it was shown that much work is being done in a number of States to stimulate the production of better seeds and to obtain a wider distribution of improved strains of high-yielding crop varieties. At this meeting the plans of several of the State seed organizations were explained and their work discussed. One noticeable thing thruout the meeting was that while all these organizations have a common purpose, the means used to bring about the desired results differ widely. In view of this fact it may be of some interest to note the plan now used by the Missouri Corn Growers' Association. The essential purposes of this plan are:

1. To stimulate the production of better seed by members of the association.
2. To test this seed and to put the association's official approval upon the best of it.
3. To advertise officially the approved seed and in every way to promote its use.

There is perfect cooperation between the Missouri Corn Growers' Association and the Field Crops Department of the College of Agriculture, and only such crop varieties as have yielded high in tests conducted by the Field Crops Department are recommended by the association and sold thru its approved list.

The first work of the association is to stimulate interest in the use of pure seeds of high-yielding varieties thru educational work. This is accomplished largely by means of a State corn show held in Columbia in January of each year, by various seed production and yield contests, and thru the work of the extension specialists in field crops, some of whom work with county agents and others with teachers of vocational agriculture in the Smith-Hughes schools. The association members are induced to secure the best seeds for planting and are then

[1] Contribution from the Missouri Agricultural Experiment Station, Columbia, Mo. Received for publication March 14, 1921.

encouraged to have the seed they produce inspected, [illegible]
and advertised for sale by the association.

In the case of all small grains, the fields are inspected by official representatives of the association just before harvesting time, for uniformity of the variety and freedom from disease and mixtures. If the field of grain comes up in quality to the high point set by the association, it is temporarily approved. After thrashing, a peck sample of seed which represents accurately the average of the entire lot is sent to the secretary of the association to be examined for purity, uniformity, cleanliness, and germination. If this meets the desired standard, the lot from which it was taken is approved and the name of the grower placed upon the approved list of the association. Corn, soybeans, cowpeas, grasses, and clovers are not inspected in the field, the approval of these being based upon an examination of representative samples of the lots of seed desired to be approved. For this purpose a 50-ear sample of corn, a peck of soybeans or similar seeds, or a quart of clover, alfalfa, or grass seeds is required.

The approved seed list has a very wide distribution. It is mailed weekly to all members of the association, to all county agents and all teachers of vocational agriculture in the State, to the departments of agronomy of all colleges of agriculture in the United States, and is included in the weekly publication of the Missouri State Board of Agriculture. The list contains the names and addresses of growers, the varieties offered for sale by each, the quantity offered for sale, together with statements of its quality and in many cases the price per bushel desired.

The seed approved is sold only under the official tag of the association, which tag complies with the Missouri seed law and gives the following information: Name of grower, kind of seed, varietal name, where grown, date tested, and percentages of germination, purity, weed seeds, and inert matter.

One very important point should be noted. The responsibility for supplying seed equal in quality to the tested sample rests solely with the grower. The association recommends the seed of a grower whose sample meets the desired standard, but does not guarantee it. This principle is clearly stated on the official tag and on each copy of the approved seed list. There is, however, a legal as well as a moral obligation that seed sold under a tag that shows its quality must reach the standard of that test. This point is taken care of by the Missouri seed law, which compels the truthful labeling of all seed packages.

The association makes no effort to fix prices on approved seeds,

tho for the sake of completeness in the published list the grower is requested to state his price. This price is generally considerably lower than would have to be paid for the same quality of seed bought from the average seed house, but is high enough to pay the grower well for the extra expense and trouble the sale has caused him. Of course, all trading is done directly between the grower and the buyer. The association does not attempt to record all sales made or keep in touch with the men who buy thru the list, except in special cases, as where selected improved strains put out by the Field Crops Department are desired to be distributed over the State at large. Such sales are recorded and all buyers are kept in touch with until the seed has become widely distributed.

It will be seen that, unlike other seed associations, the Missouri Corn Growers' Association does not undertake the production and distribution of limited quantities of "pedigreed" seed, nor does it undertake to sell thru a difficult and rigid system of certification. It does, however, serve as an agency to distribute and increase superior strains produced by the Field Crops Department of the Missouri Agricultural Experiment Station.

To the advantage of both the grower and the buyer, the farmers of this State are put in touch with large quantities of the best seed that can be found in Missouri. It is, therefore, the purpose of the association not only to stimulate the production of good seed, but also to develop its approved seed project until the larger part of Missouri's crops are annually planted with the highest grade seed obtainable in the State.

FREQUENCY AND IMPORTANCE OF FIVE-LOCK BOLLS IN COTTON.[1]

HENRY DUNLAVY.[2]

The varieties and strains of cotton found within the American Upland group are characterized by having 4-lock and 5-lock bolls. Occasionally a 3- or a 6-lock boll is found, but these are very scarce and of no commercial importance. Of 20,266 bolls of Acala cotton examined by the author only three 3-lock and two 6-lock bolls were found. These were all found within one pure-line strain.

There is a well-founded partiality in the minds of the planters in favor of a cotton that produces a high percentage of 5-lock bolls. This is reflected in the question often asked by growers, to which the

[1] Received for publication July 29, 1921.

[2] Plant breeder, Watson Cotton Seed Company, Waxahachie, Texas.

answer too frequently is: "This is a pure 5-lock cotton." None of the varieties of the American group produces 100 percent "fives," tho some varieties and strains undoubtedly have a tendency to produce a much higher percentage than others. Individual plants have been found that produce all 5s, but the plants produced from this seed were found to have some 4-lock bolls.

The desire of the planter for a cotton that will produce a high percentage of 5-lock bolls is well founded from the fact that they are heavier than the 4-lock bolls. From the weighing of 1,186 5-lock bolls and 725 4-lock bolls it was found that the 5-lock was 11.24 percent heavier than the 4-lock. From this it can be seen that the individual lock of the 4-lock boll is larger than that of the 5-lock, as the 5-lock contains 20 percent more locks and only about half this percent more weight.

Table 1 shows the percentage of 5-lock bolls at the first, second, and third pickings. These data are from 24 rows of Watson Acala cotton grown in 1920 near Italy, Texas, together with the average for each picking and the average for each row. Each row was planted with seeds from an individual plant selection in 1919. A total of 10,581 bolls were studied, of which 7,764 contained 5 locks.

TABLE 1.—*Percentage of 5-lock bolls at first, second, and third picking in Acala cotton, together with averages.*

Row.	First picking.	Second picking.	Third picking.	Average.
1	70.42	76.34	46.19	62.97
3	95.37	86.23	81.94	86.25
7	90.56	84.54	69.10	78.82
8	88.88	70.16	54.28	67.84
9	92.98	84.78	76.41	84.88
11	93.44	84.56	64.61	76.80
12	85.24	62.82	46.91	56.97
13	77.55	70.88	56.00	65.54
14	100.00	94.24	96.73	95.88
16	88.23	72.19	65.29	72.64
19	91.46	86.98	66.38	80.98
23	80.00	71.01	57.89	67.56
24	96.72	91.74	80.98	88.91
26	96.05	77.77	61.29	73.90
30	90.56	85.00	60.59	73.79
34	82.05	80.35	62.33	69.63
39	83.09	82.74	63.01	75.46
42	91.22	80.54	66.38	74.83
43	90.62	76.39	55.21	66.93
44	87.41	73.22	66.96	74.51
45	91.15	76.61	70.79	78.92
46	64.19	54.82	39.97	51.45
48	90.81	85.53	68.08	80.65
49	70.73	53.22	35.07	52.49
Average	87.05	78.19	62.39	73.38

It is readily seen that, with two exceptions (numbers 1 and 14), the highest percentage of "fives" is found in the first picking; the next highest in the second picking; and the lowest percentage in the last picking. The first picking averaged 87.05 percent of 5-lock bolls, ranging from 64.19 to 100 percent. The second picking averaged 78.19 percent of 5-lock bolls, ranging from 53.22 to 94.24 percent. The third picking averaged 62.39 percent of 5-lock bolls, ranging from 35.07 to 96.73 percent. The average of all plants at all pickings was 73.38 percent of 5-lock bolls, ranging from 51.45 to 95.88 percent.

These results are very pronounced and tend to vindicate the producer in his persistent desire for a cotton that produces a high percentage of 5-lock bolls.

HOME-GROWN AND IMPORTED RED CLOVER SEED.[1]

R. G. WIGGANS.[2]

On account of the very large importations of red clover seed during the past few years, the relative values of seed from different sources becomes very important. A test of red clover seed from three different sources was made at the New York State College of Agriculture in 1920. The results of the year's test are shown in Table 1.

The first and probably the most significant point in the table is the estimated stand after the first winter. The Italian-grown seed used in the test produce nonhardy plants for New York conditions, not having sufficient hardiness to withstand a mild winter such as that of 1920–21. The French clover was only slightly less hardy than the native grown. It should be said in this connection that a satisfactory growth was made during the first summer and that a perfect stand was secured in all plats.

All weights given in the table are actual dry weights as determined by drying 20-pound samples to dryness. The differences in the yields correspond very closely to the estimated stand, altho the green weight of the French type was relatively higher, due to its being a little larger and later. This was shown also by its smaller percentage of dry matter.

The results of this seeding, therefore, indicate that red clover grown from Italian seed winterkills easily under New York conditions, and that it is somewhat doubtful if seed from France should be used if native-grown seed can be obtained.

[1] Contribution from the Cornell University Agricultural Experiment Station, Ithaca, N. Y. Received for publication November 4, 1921.

[2] Assistant professor of farm crops, Cornell University.

TABLE 1.—*Winter survival, dry weights per plat, and other data obtained from clover grown from native, French, and Italian seed at Cornell University in 1920 and 1921.*

Source of seed.	Estimated stand after first winter.	Dry weights per plat. First cutting. Series 1.	First cutting. Series 2.	Second cutting. Series 1.	Second cutting. Series 2.	Dry weight per acre for season.	Estimated percentage of total yield as clover	Dry weight of clover per acre.
	Percent.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*
Native (Mich. grown)	90	52.8	57.1	30.4	27.7	6,770	98	6,635
French	80	49.9	50.3	29.3	22.7	6,088	98	5,966
Italian	5	21.3	18.1	24.0	20.2	3,344	10	334

AGRONOMIC AFFAIRS.

TORONTO MEETING OF THE SOCIETY.

A program meeting of the American Society of Agronomy will be held on December 29, 1921, at Toronto, Ontario, in connection with the meeting of the American Association for the Advancement of Science which will be held there during the week beginning December 26. On the preceding afternoon, December 28, the meeting of Section O (Agriculture) of the association will be held, and on the evening of December 28 Section O and the American Society of Agronomy will have a joint dinner at a place to be announced during the session. All members of the Society who can attend these meetings, especially all members in Canada, are urged to do so. A cordial invitation is extended to Canadian agrononomists who are not now members of the Society.

MEMBERSHIP CHANGES.

The Society continues to show a slow but steady growth. The number of members previously reported was 647. Since that report was written 7 new members have been added, 1 has been reinstated, 1 member has resigned, and 1 member has died, making a net gain of 6 and a present membership of 653. An encouraging fact is that the library subscription list, and particularly the foreign list, is constantly growing.

NOTES AND NEWS.

C. D. Davis has been appointed assistant professor of farm crops at the Kansas college.

Alva C. Hill has been made assistant in field crops at the University of Missouri.

Kristen Skovgaard, who has been engaged in postgraduate study at Iowa State College and at Cornell University during the past year and a half, has returned to Denmark and is now located at Frennegard, Harshblin.

A. E. McClymonds, formerly extension agrononist in Colorado, is now superintendent of the Aberdeen (Idaho) substation.

M. A. Beeson has been elected dean of the college of agriculture of Oklahoma, and C. T. Dowell has been made director of the experiment station. W. A. Conner is now director of extension in that State.

Dr. John L. Coulter, for the past several years dean and director of the West Virginia College and Station, has been elected president of the North Dakota Agricultural College, and has entered on his new duties.

W. H. Dalrymple has resigned as director of the Louisiana station on account of ill health, and was succeeded on October 10 by W. R. Dodson, who resigned from this position about a year ago to engage in commercial work.

G. F. Freeman, for the past three years cotton breeder for the Société Sultanienne d'Agriculture at Cairo, Egypt, is now chief of the division of cotton breeding at the Texas station.

David Friday, professor of economics and finance at the University of Michigan, has been appointed president of the Michigan Agricultural College, effective January 1. F. S. Kedzie, the retiring president, has been made dean of the department of applied science.

P. L. Gile, formerly associated with the American Agricultural Chemical Co., is now in charge of the soil chemistry investigations of the Federal Bureau of Soils.

J. W. Gilmore, professor of agronomy in the California College of Agriculture, has returned from the University of Chile, where he has been exchange professor for the past six months.

J. B. Thompson, specialist in forage crops at the Florida station, resigned August 9 to become agronomist in charge of the Virgin Islands Experiment Station.

J. J. Thornber, professor of botany in the University of Arizona, succeeded D. W. Working as dean and director of the agricultural college and station of that institution on September 1.

JOURNAL

OF THE

American Society of Agronomy

VOL. 13. DECEMBER, 1921. No. 9

THE AGRONOMIC PLACEMENT OF VARIETIES.[1]

C. A. MOOERS.[2]

Both the botanist and the agronomist are interested in plants, but their points of view are different. The principal interest of the botanist lies in taxonomy, histology, physiology, or some subject other than the productiveness of the plant, whether of foliage or fruit. To the agronomist, on the other hand, production, or yield per unit area is the fundamentally important consideration. The agronomist, therefore, pays much attention to varieties, with regard to both yield and quality of product and to the means whereby they may be improved. He also gives special heed to numerous other factors which affect yield, such as time and rate of seeding, soil preparation and adaptability, fertilizers, and soil bacteria. Thruout, crop yield is the central thought and is, in fact, the tie that binds agronomists together.

Every branch of science goes naturally thru certain stages of development. There is the preliminary gathering of data and their assembly to try out various hypotheses, and in time the subject is placed on a scientific basis with attendant theories, mathematical formulas, etc. Agronomy has been defined as that branch of agriculture which treats of the theory and practice in the production of farm crops. This definition appears to fit the present situation, for agronomy as the science of crop yield has advanced little beyond the

[1] Presidential address of the American Society of Agronomy. Presented before a joint session of the American Society of Agronomy and the Society for the Promotion of Agricultural Science at New Orleans, La., November 8, 1921.

[2] Agronomist and vice-director, Tennessee Agricultural Experiment Station, Knoxville, Tenn.

data-gathering stage. As long as this is true it remains under a certain ban. Devotees of so-called pure science speak lightly of it. Students complain of the many exceptions and precautions and of the general lack of solid foundation. Such a condition puts the agronomist on the defensive and makes his subject less attractive to those who might specialize in it. However this may be, I am sure that every advance toward a scientific basis is welcomed by all. I will go a little farther and say that I believe the time has come, first, for the improvement of certain of our methods of field experiments with a view to scientific accuracy; second, for progress in getting agronomy onto an exact, or mathematical, basis. I have especially in mind a subject that has often been looked upon with distrust or considered as a sort of necessary evil. I refer to varietal experiments.

The American farmer produces annually crops valued into the billions of dollars. A very slight percentage increase would under usual conditions result in a large increase in aggregate value. The experimental agronomist has full faith in the superiority of certain varieties over others. Thru the Division of Extension and other agencies he has great influence in determining the variety the farmer shall grow. The setting is right, therefore, for the practical application of what appear superficially to be plain, simple data from the apparently simple varietal experiments. On the other hand, it is not difficult to find good support to the view that for large sections of the country it is a question whether the yields would be increased or diminished were the farmers to follow so-called authoritative advice in the choice of varieties for some of our staple crops. In the study of bulletins on corn the writer has been impressed with the fact that authors are inclined to draw their main conclusions from only the more recent experiments, the inference being that the old data are unreliable, or, so to speak, out of date. At the North Carolina station the writer was told that varietal trials, as conducted in the past, had been discontinued because considered to give information that was more or less misleading. In their place special attention was given to corn improvement in communities thru clubs which utilized the best local varieties. Varietal trials were conducted, but with regard only to local conditions, the community club being the chief, or final, judge of the results obtained. The following statement is made by Carrier:[3]

A great many experiments with corn have been conducted, and the published results are voluminous. It is very disappointing, however, to try to

[3] Carrier, Lyman. A reason for the contradictory results in corn experiments. *In* Jour. Amer. Soc. Agron., v. 11, no. 3, p. 109. 1919.

summarize these data, especially if the results are given in terms of grain. The summary often presents a quantity not sufficiently positive or negative to prove anything.

In explanation of the unreliability of varietal trials Carrier lays stress on the effect of xenia, and presents evidence to show that kernels resulting from cross pollination between varieties are, as a rule, appreciably heavier than the others and may materially affect the outcome of a trial. Both the teachings on the subject of varieties at our leading universities and agricultural colleges and the facility with which bulletins on varietal trials find the waste basket point to a lack of confidence in work of this character. This situation is to our discredit as agronomists, and the removal of the charge would do much toward increasing our standing not only with other scientific workers, but also with the farmer.

I now face the difficult task of attempting to outline the essential requirements in the placing of our agronomic knowledge of varieties on a scientific basis. I have in mind a basis which will, for example, allow a mathematically accurate selection of a variety for a given set of conditions, enable us to tell closely the number of days to maturity from a given date of planting, and calculate exactly the best number of plants per acre for the highest yield and best quality of product. I do not pretend, however, to have solved all of the problems involved, but I shall try to establish some new points of view and to indicate certain features which appear to me to be essential to the successful solution of the problem as a whole.

For various reasons, but chiefly because of having at hand a fairly large amount of data, I have taken varieties of corn as an example.

Sources of Error in the Conduct of Varietal Experiments with Corn.

I desire to call your attention briefly to the more important sources of error, as I see them, in the conduct of varietal trials, for trustworthy field data are of fundamental importance in the solution of our problems.

NUMBER OF EXPERIMENTAL PLATS.

All agronomists will agree that uniformity in soil productiveness is highly important. Unfortunately most of us have found that it is hard to get. The experimental tract can be manured, plowed, and prepared in a uniform manner; the planting, cultivation, and harvesting can be done so as to be fair for all varieties; but the natural inequalities of the soil prove a source of error to be overcome. There-

fore, replications are required. The number is debatable, but I will suggest three; that is, three plats for each variety in the series are needed in order to judge its comparative value as a grain producer.

NECESSITY OF THE RIGHT STAND FOR EACH VARIETY.

Some years ago I called attention to the importance of the proper adjustment of the stand to suit the special requirements of every variety.[4] Data obtained since then emphasize the importance of this factor, as may be seen in Table 1 from trials on fertile bottom land at the Tennessee station at Knoxville.

TABLE 1.—*Average yields per acre of typical varieties of corn at each of three rates of planting from twelve crops grown from 1906 to 1915.*

Variety.	6,000 plants.		8,000 plants.		10,000 plants.	
	Grain.	Stover.	Grain.	Stover.	Grain.	Stover.
	Bushels.	*Tons.*	*Bushels.*	*Tons.*	*Bushels.*	*Tons.*
Albemarle	70.9	2.44	69.6	2.60	68.1	2.78
Huffman	68.4	3.31	64.0	3.31	60.4	3.77
Hickory King	55.5	1.83	61.9	2.07	69.4	2.32

In this table are shown the results from three typical varieties: Huffman, Albemarle, and Hickory King. Along with Huffman would be included a number of large late-maturing varieties, such as Shaw Improved and Higgs. With Hickory King would be grouped Boone County White, Reid Yellow Dent, Piedmont White Dent, and many others. With Albemarle are found Cocke, Marlboro, and other true prolifics, which have a marked adaptability to rather wide variations in rate of planting, or stand, without change in the grain yield as indicated in Table 1.

Had only the 6,000 rate been used, the logical conclusion would be that Albemarle was first in grain yield, that Huffman was a close second, but that Hickory King was far outclassed by the other two. At the 8,000 rate Albemarle is easily first; Huffman is second, with an average production of 5.6 bushels less than Albemarle; and Hickory King is third, but only 2.1 bushels per acre less than Huffman. At the 10,000 rate Hickory King is first, Albemarle a close second, yielding 1.3 bushels less, and Huffman a poor third, lacking 9 bushels per acre, on the average, of equaling Hickory King. With examples like

[4] Mooers, C. A. Stand and soil fertility as factors in the testing of varieties of corn. Tenn. Agr. Expt. Sta. Bul. 89. 1910.

these before us, and they are typical of many that could be cited, are we not warranted in saying that the rates of planting in a varietal trial must conform to the requirements of each individual variety? Since this is generally unknown, several rates of planting so as to cover the possible range of requirements are usually necessary.

NUMBER OF ROWS PER PLAT.

The number of rows per plat is another item that deserves more attention, but I have no special evidence on the subject. At some stations very narrow plats, with only one or two rows, have been used. If varieties of widely different habits of growth be planted side by side, shading effects, detrimental to the smaller variety, would be expected. This and other sources of error could be reduced by the use of, say, 6-row plats with an extra outside, or guard, row on each side.

DURATION OF TRIAL.

The duration of the trials is an important matter that has not been settled. Results given in a recent Missouri bulletin[5] show that eight years were required in some series in order to establish the relative order of yield of the varieties grown. The value of methods which would cut down the time required to reach reliable conclusions is evident.

THE VALUE OF A CONSTANT STANDARD VARIETY.

The value of a fixed standard variety, and not a fluctuating standard, due either to changes brought about by selection and breeding or to widely different sources of seed, appears not to be fully recognized. For reasons that will be presented later, I believe that the standard variety should receive the same strict attention by the agronomist as the standard acid by the analytical chemist.

LOCALITY AND SOIL PRODUCTIVENESS IN THE INTERPRETATION OF DATA.

In the discussion of data from varietal trials the general and almost universal point of view is locality; that is, if a certain variety gave the best yields at a certain place, it is assumed to be especially adapted to the climate and soils of the surrounding country. As a rule, a State is divided into large districts, and the varieties recommended for each are those that have given the highest yields under, perhaps, only one soil condition; that is, the soil may have been rich, medium, or poor

[5] Stadler, L. J., and Helm, C. A. Corn in Missouri. Mo. Agr. Expt. Sta. Bul. 181. 1920.

as to productivity. If the soil happened to be typical of the whole district, the conclusion reached may be justified; but if the soils of the district differ widely in productivity, or if the soil used in the experiments be either much better or much poorer than the average, what then?

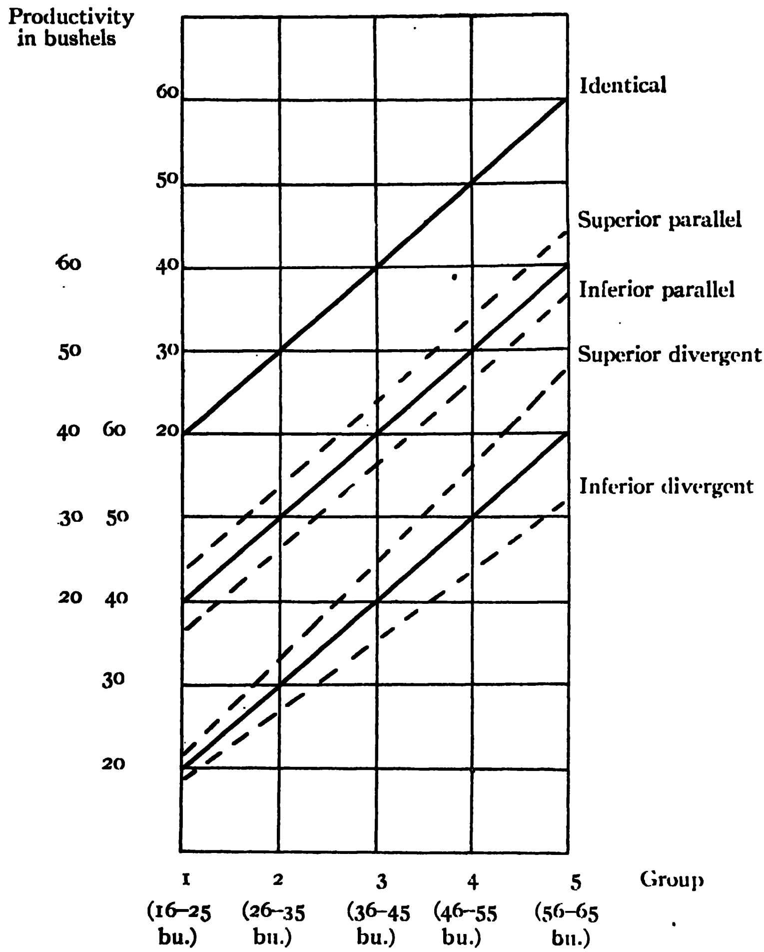


FIG. 17. Hypothetical relationships between varieties with respect to yield as induced by varying degrees of soil productivity.

SOME HYPOTHETICAL VARIETAL RELATIONSHIPS.

Recent study of data obtained at the Tennessee station during the past 15 years has convinced me that we must consider the relative standing of varieties from what I believe to be a new point of view,

which I have had the pleasure of developing for this occasion. First I outlined some hypothetical relationships between varieties of corn as grain producers on soils of various degrees of productivity. To illustrate them I have prepared figures 17 and 18, in which the ordinates

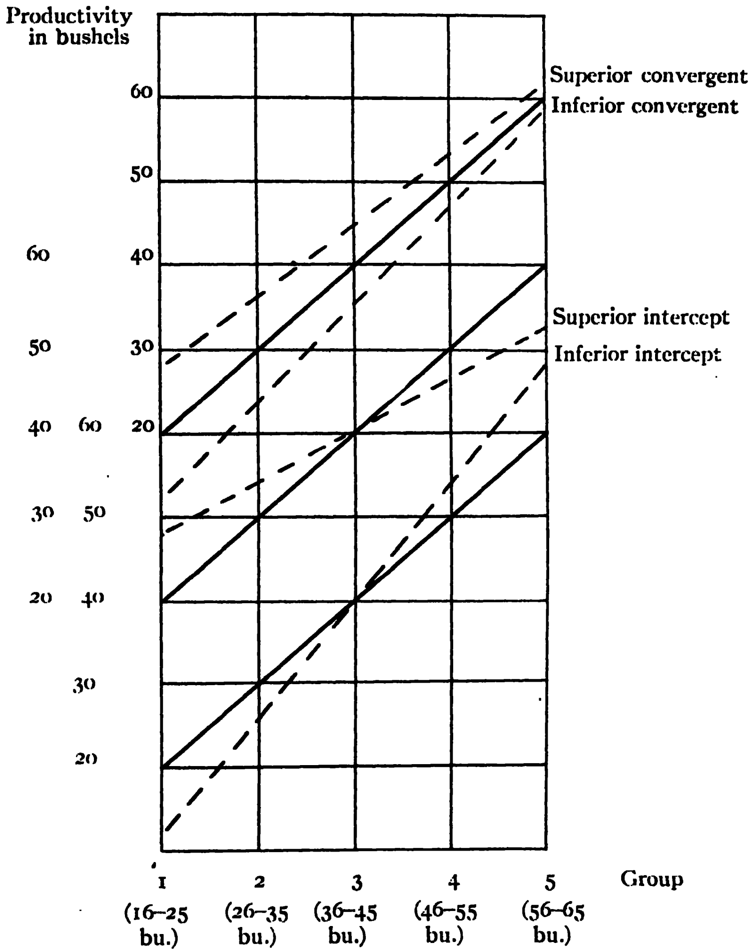


FIG. 18. Hypothetical relationships between varieties with respect to yield as induced by varying degrees of soil productivity.

show soil productivity conditions in terms of grain per acre and the abscissas show averages from group yields for soils of various degrees of productivity. As arranged the groups are 15–25 bushels, 26–35

bushels, etc., based on the yield made by the standard variety. If the trials be numerous enough, the curve for the standard variety will by the conditions be a straight line passing as shown thru the intersections of the coordinates. Now, let the yields made by another variety in the same series of experiments be grouped, not according to the conditions laid down for the standard, but according to the yields obtained regardless of size. For example, if the standard makes, in a 5-year trial on a poor soil, yields between 15 and 25 bushels per acre, with an average of 20 bushels, another variety tested in the same series might make an average of, say, 26 bushels; and tho the majority of the yields might have been more than 25 bushels, the point would be located on the group 1 ordinate. In a like manner a point would be located for each of the other groups. The question now arises as to the form of the curve of a variety grown in comparison with the standard. Let us assume it to be a straight line. There are then the following possibilities, provided the standard is a medium yielder.

1. A variety making yields which under all conditions are practically identical with those made by the standard. Such a variety I have designated, with reference to the standard, as an **identical.**

2. A variety outyielding the standard by a nearly constant amount under widely different conditions of productivity I have designated as a **superior parallel.**

3. In a similar manner a variety might be an **inferior parallel,** because surpassed by the standard by a nearly constant quantity on all kinds of soils.

4. A variety surpassing the standard under all conditions, but the difference between them increasing with an increase in productivity, I have designated as a **superior divergent.**

5. In a similar manner a variety might be an **inferior divergent** because surpassed by the standard, the difference increasing with the increase of soil productivity.

6. A variety surpassing the standard under all conditions, but to the greatest extent under conditions of low yield, I have designated as a **superior convergent.**

7. An inferior variety showing its widest divergence under poor land conditions, but tending to approach the standard under rich land conditions, would be an **inferior convergent.**

8. A variety superior under conditions of low yield, but inferior under conditions of high yield, I have designated a **superior intercept.**

9. A variety inferior under conditions of low yield, but superior under conditions of high yield, is designated an **inferior intercept.**

Experimental Evidence.

Let us now notice the results bearing on this subject obtained in experimental trials conducted in various parts of Tennessee. In these comparisons, however, no distinction was made between yields due to the favorableness or unfavorableness of a season and those due to the degree of productiveness of the soil under average conditions; that is, the curve for the standard was determined by averaging all the yields obtained within the group limit, regardless of whether the soil or the season was the prominent factor in bringing about the yield obtained, or both soil and season. Differences in soil productivity were, however, the chief cause of the variation. Table 2 and figures 19 to 23 show the results obtained in the longest continued and nearest complete experiments. In this connection it should be noted that the experiments were made in various parts of the State, including east, middle, and west Tennessee, and at elevations from 360 to 1,850 feet. Practically all the very high yields were obtained at the Knoxville station, on rich bottom land. The very low yields nearly all came from the Cumberland Plateau and the Highland Rim of middle Tennessee. The medium yields come from various localities over the entire State. In these trials Hickory King, a medium yielding variety, of easy identification and well established in the State, was used as a standard and is shown as the solid line in the figures.

Table 2.—*Results from varietal experiments with corn in Tennessee summarized with regard to yields of grain in bushels per acre.*[a]

Variety.	Group, determined with regard to Hickory King as a standard.						
	1 (10-25 bu.).	2 (26-35 bu.).	3 (36-45 bu.).	4 (46-55 bu.).	5 (56-65 bu.).	6 (66-75 bu.).	7 (76 bu. up).
Hickory King	22.3^{10}	30.7^{16}	39.8^{34}	49.4^{15}	57.1^{8}	68.6^{2}	80.6^{2}
Leaming	21.5^{10}	27.0^{16}	31.9^{34}	43.1^{15}	49.1^{8}	56.8^{2}	67.4^{2}
Hickory King	22.7^{6}	28.7^{7}	41.2^{16}	50.5^{7}	55.2^{1}	69.6^{2}	76.6^{2}
Neal Paymaster	26.0^{6}	35.1^{7}	49.3^{16}	58.6^{7}	69.9^{1}	78.3^{2}	95.0^{2}
Hickory King	22.3^{10}	30.0^{13}	41.4^{16}	50.7^{7}	58.9^{6}	69.2^{4}	78.6^{4}
Albemarle	20.9^{10}	30.7^{13}	45.1^{16}	54.4^{7}	65.5^{6}	73.3^{4}	93.2^{4}
Hickory King	22.4^{8}	29.5^{7}	40.6^{14}	50.9^{5}			
Piedmont White Dent	27.8^{8}	37.0^{7}	43.3^{14}	52.3^{5}			
Hickory King	22.8^{5}	31.0^{9}	39.8^{26}	49.8^{8}	58.8^{10}	69.2^{4}	78.6^{6}
Huffman	21.1^{5}	27.0^{9}	40.9^{26}	48.0^{8}	57.3^{10}	68.8^{4}	90.7^{6}

[a] Superior figures show the number of trials averaged.

Figure 19 shows that Leaming, in comparison with Hickory King, is an inferior divergent—that is, it yields less than Hickory King under all degrees of productivity—but as the soil productivity increases the

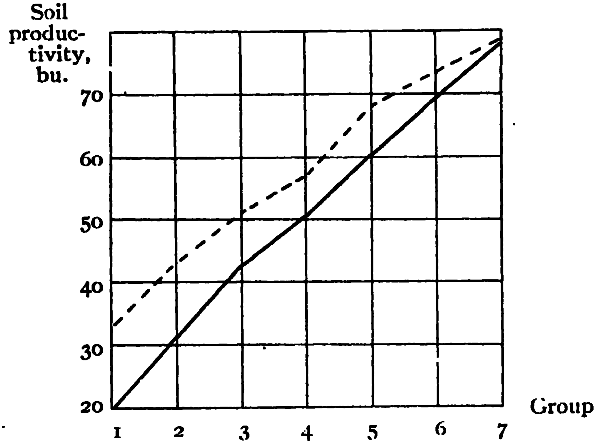


FIG. 19. Comparison of yields of Leaming and Hickory King.

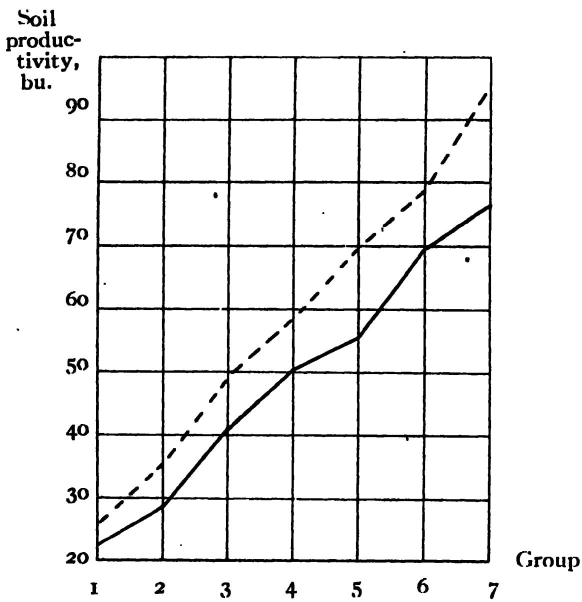


FIG. 20. Comparison of yields of Neal Paymaster and Hickory King.

greater is the difference between the yields of the two varieties. Figure 20 shows that Neal Paymaster behaves as a superior divergent to Hickory King, because as the soil productivity increased the greater is

its lead. Figure 21 shows that up to a production of about 28 bushels Albemarle is inferior to Hickory King, but thereafter it is superior. In other words, Albemarle as compared with Hickory King is an in-

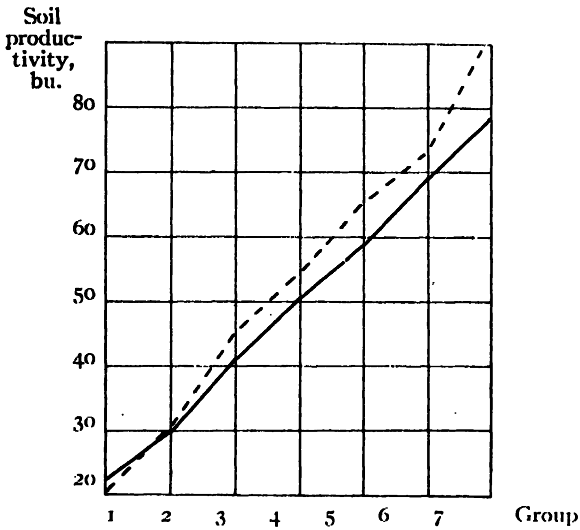


FIG. 21. Comparison of yields of Albemarle and Hickory King.

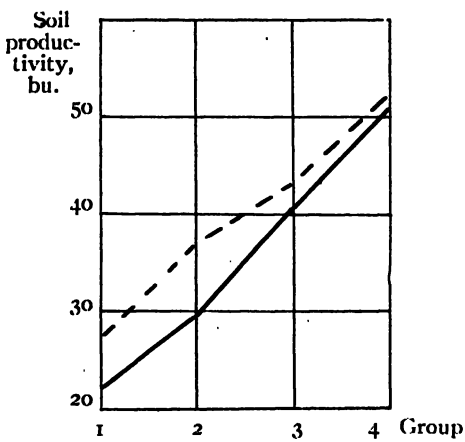


FIG. 22. Comparison of yields of Piedmont White Dent and Hickory King.

ferior intercept. In figure 22 Piedmont White Dent appears to be a continued, but unfortunately without regard to the best rate of planting superior convergent as compared with Hickory King. In figure 23

Huffman is compared with Hickory King. The comparison was long for each variety. The information is now available to show that Huffman should be planted relatively thin and Hickory King relatively thick. This may account for the lack of a more positive direction for the Huffman curve. Probably this variety is an inferior intercept as compared with Hickory King. On the other hand, should the peculiar form of the curve obtained be verified by later experiments, locality adaptability would seem to be indicated. Results like these can not be attributed to chance. The curves conform too closely to straight lines

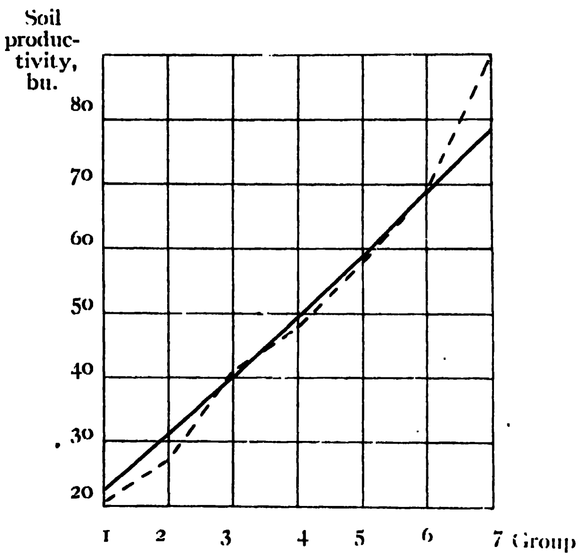


FIG. 23. Comparison of yields of Huffman and Hickory King.

for that. I conclude, therefore, that the data at hand are very strong evidence that one variety may bear toward another any one of the simple relationships indicated in the nine hypothetical relationships; that is, the curve showing the relationship as to grain production between one variety and another, taken as a standard, approaches a straight line and has a definite position with regard to a standard. This conclusion is of greatest importance wherever the growing season is long, permitting widely different varieties to mature. The experimental work entailed in the determination of varietal place should not prove a serious obstacle, because only two series of experiments are needed, viz., one on rich land and one on poor land, for in this way the two points necessary to locate a straight line would be obtained.

I can not refrain from calling attention to the fact that the usual assumption implied in varietal bulletins up to the present time is that a variety is either an identical, a superior parallel, or an inferior parallel, no attention being given to any of the other six possibilities. I see no special reason why any of the first three relationships should occur oftener than any of the others.

Also I will digress to call attention to the large error that may be produced in field experiments by changing from a soil of low productivity to one of high productivity, if the yields from both are to be about, for instance, by the heavy manuring of the experimental range gathered under a single average. Such a condition could be brought which was previously of low or moderate productiveness. This heavy manuring, coupled with a single very favorable season, might easily throw the result as a unit series entirely out of joint and lead to very erroneous conclusions.

The Date of Maturity of a Variety.

An accurate method of calculating the date of maturity of a given variety when planted at a given time and place is desirable in farm practice, especially in the South, where the period of planting extends over three or even four months. Figures 24 to 26 show the curves plotted from the results of date-of-planting experiments conducted for some ten years at the Tennessee station for each of three distinct varieties of corn, Leaming an early, Hickory King a medium, and Huffman a late maturing variety. By the aid of these curves the probable date of maturity for any date of planting is easily determined. I wish to call attention to an interesting feature of these curves. They appear to be not only arcs of a circle, but of a circle having the same radius, but with differently located centers, as may be seen in figure 27. The curves were plotted separately on coordinate paper and without any thought at the time that they would prove to be arcs of a circle, not to mention of the same circle, but when superimposed the three curves were found to coincide almost perfectly and to form the arc of a circle having a radius nearly nine times the length of one of the coordinate squares of the system shown in the figures. It remains, of course, to be determined over what geographical limits this finding is substantially true. It is possible that dates of planting and maturity as obtained in the usual varietal trials might be utilized in the locating of this arc with sufficient accuracy for practical purposes.

THE PRODUCTIVE VIGOR OF A VARIETY.

Another important factor relating to the placement of varieties needs to be determined, and that is what I will call the **comparative productive vigor** of a variety thruout its possible climatic range. So far as I am aware, this problem has not been seriously investigated, but I believe it capable of satisfactory solution. The indications are that a variety will have similar rating over a large area. At any rate, many could be mentioned whose high yielding capacities are not limited by the boundaries of several States, not to mention counties in a State,

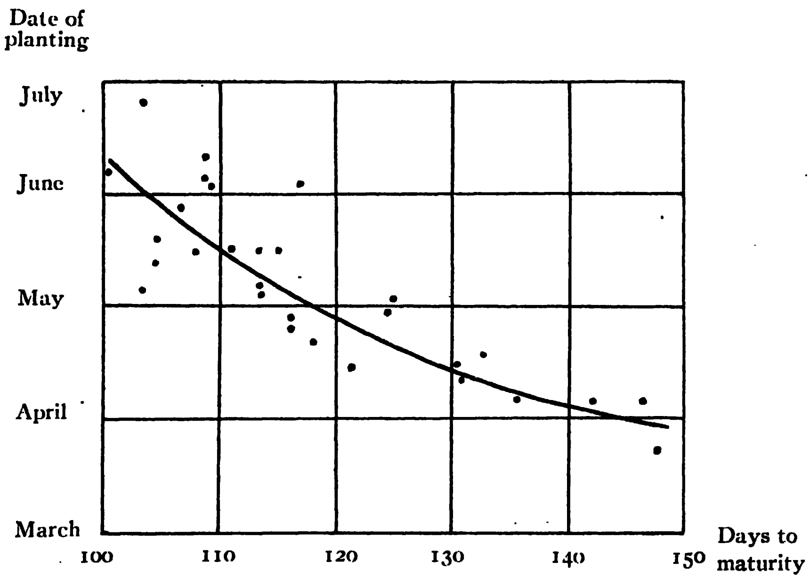


FIG. 24. Maturity graph for Leaming.

but there are probably limitations other than mere length of season and general productivity conditions. I refer to the effects of such factors as length of day, temperature, and humidity of the air to the physiological peculiarity of a variety and to the physical character of the soil.

SUMMARY.

In conclusion, I will summarize the situation as follows. The fourth paragraph of the summary relates, however, to a matter barely mentioned previously, but is germane to the general subject.

1. Certain improvements are needed in the conduct of varietal trials with a view to scientific accuracy. Increased attention should be given

to at least the following points:

a. The proper stand for each variety.

b. The importance of a standard variety.

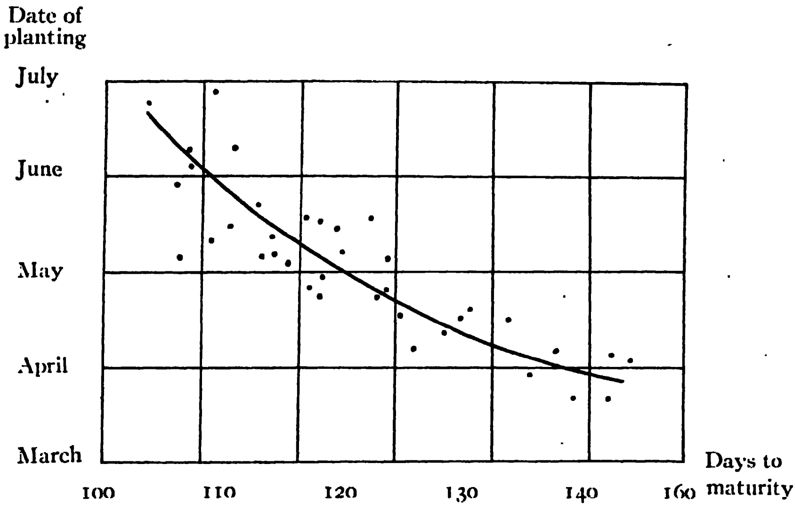


FIG. 25. Maturity graph for Hickory King.

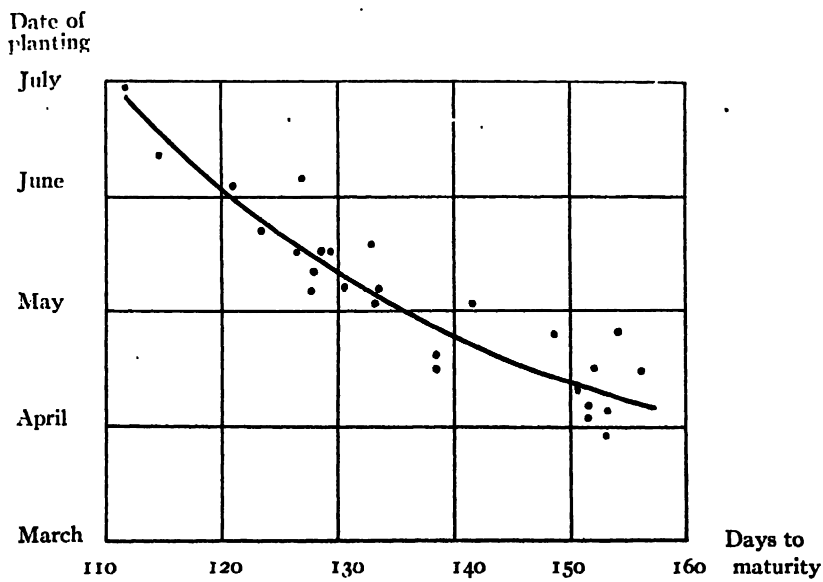


FIG. 26. Maturity graph for Huffman.

c. The necessity of conducting varietal trials on soils which are truly representative of productivity conditions of the region to which the results are to be applied.

2. Nine simple relationships appear to exist between varieties of corn with regard to grain production on soils differing in productiveness. The location of varietal curves with reference to a standard will make possible better founded and more accurate selection of a suitable variety for a given condition.

3. Data from date-of-planting experiments enable the plotting of a curve by means of which the approximate date of ripening of a variety can be predicted with a fair degree of accuracy. All three of the curves obtained, one each from an early, a medium, and a late maturing variety, appeared to be arcs of a circle with the same radius, but with different centers.

4. A practical method[6] of calculating the most favorable number of plants per acre has been worked out, the variety to be grown and the productiveness of the soil in the average season being the factors taken into consideration. The range of its adaptability and all necessary modifications to give it wider application need to be determined.

5. There remains to be determined in particular the productive vigor of every important variety over its possible territorial range. With this factor in hand we would, as I am viewing the subject, be able to say that a scientific basis for the agronomic placement of varieties not only of corn but of other crops was on the high road to successful completion.

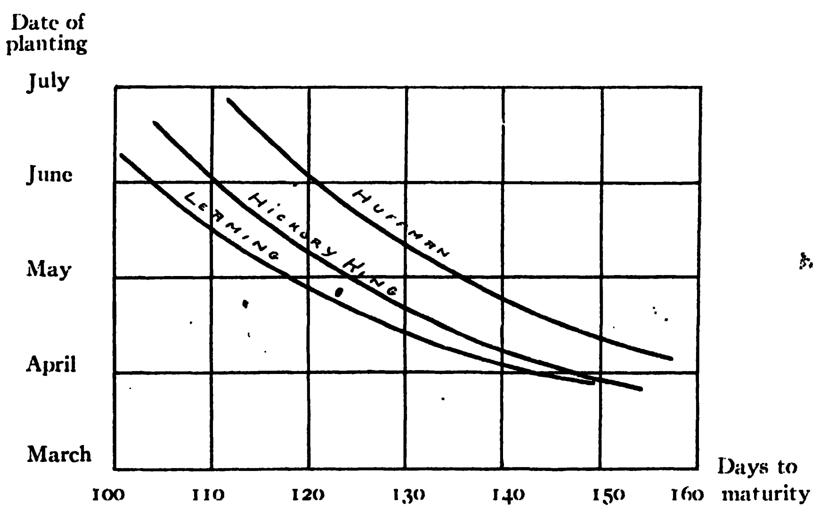


FIG. 27. Comparable location of maturity graphs for three varieties of corn.

[6] Mooers, C. A. Planting rates and spacing of corn under Southern conditions. *In* JOUR. AMER. SOC. AGRON., v. 12, no. 1, p. 1–22. 1920.

RELATIVE GROWTH RESPONSE OF CROPS TO EACH FERTILIZER INGREDIENT AND THE USE OF THIS RESPONSE IN ADAPTING A FERTILIZER ANALYSIS TO A CROP.[1]

Burt L. Hartwell.[2]

Before considering the special needs of the various crops brief reference should be made to the different progressive, or perhaps retrogressive, agricultural conditions under which crops in general have obtained the food absorbed from the soil medium.

The farmer first solved the problem of crop feeding by selecting virgin soil from which the roots could secure the entire needs of the plants. Later he learned that it was better practice to spread on the land the refuse from his animals than to dump it into the river. He was slow to admit that the soil of his choice could possibly deteriorate, but, instead, he delighted in advertising the inexhaustible fertility of his broad acres.

The failure of certain crops to yield as much as formerly has led to their production on newer lands by the next group of pioneer farmers. As the population increased around his farm he has been willing to accommodate the livery stables by removing their refuse from time to time and spreading it on his land. He might be persuaded to use a little lime or some source of phosphorus with his manure, but he wanted you to distinctly understand that fertilizers were absolutely unnecessary in his favored locality.

Having finally learned to recognize the value of animal manures, perhaps even to the extent of conserving them, it was a rude shock to find that one source of animal manure was gradually being replaced by other methods of locomotion which unfortunately yielded no valuable by-product for his land. A little fertilizer in the drill then came to be recognized as a useful " stimulant," to be applied sparingly, however, lest it poison the soil.

Slowly the idea spread that some soils were actually deficient in one or more nutrients, and the general public still holds firmly to the belief

[1] Presidential address of the Society for the Promotion of Agricultural Science. Presented at a joint session of that Society and the American Society of Agronomy at New Orleans, La., November 8, 1921. Contribution 284 of the Agricultural Experiment Station of Rhode Island State College, Kingston, R. I.

[2] Director and agronomist, Agricultural Experiment Station of Rhode Island State College.

that it is only necessary to analyze the soil before planting in order to find out just what fertilizer is needed to supply those deficiencies. It has not occurred to the public that the contributions which mother earth makes are tremendously influenced by the weather, and that until this can be predicted satisfactorily the chemist can not be expected to tell what will be needed to supplement its immediate effects.

In deciding upon the general composition of fertilizers the manufacturer was influenced by the fact that the soil, as well as the animal manures which his mixture was to supplement, contains a relatively small amount of phosphorus. These considerations and the cheapness of sources of this element led to a very liberal proportion of phosphorus in the fertilizers. Four to five times as much of this ingredient as the crop removed has been used, and economically, too.

In their relation to the rapidly disappearing manure, fertilizers must be looked upon more and more as substitutes rather than supplements. A 4:8:4 fertilizer (that is, 4 percent of total ammonia, 8 of "available" phosphoric acid, and 4 of water-soluble potash) has been popular where more or less manure was to be had. When it is recalled, however, that, on the basis of total ingredients, 5 tons of manure represent a 6:3:5 fertilizer, it seems probable that, to replace entirely the highly ammoniacal and potassic animal manure, fertilizer analyses will be changed materially and the ammonia and potash be increased relative to the phosphoric acid. As a general relation 2:4:2, for example, may be changed to 2:3:2.

It seems probable that the current practice of applying phosphorus far in excess of what the crop removes will eventually modify the soil so that the deficiency of phosphorus will not exceed that of the other fertilizer elements. If such a condition should develop, any differentiation in the relation of the ingredients of a fertilizer would then be determined only by differences in the growth response of individual crops.

The farmer has held the idea from the time when fertilizers first appeared that a given crop should receive a fertilizer especially adapted to it. Whatever may be our ideas concerning the scientific reasoning of the farmer, we do well to appreciate his power of observation. He had only to watch the growth of the plants to satisfy himself that they did not all respond alike to the different materials which he added to the land.

The fertilizer manufacturer was not slow to see the economic advantage of complying with this demand. There arose a great variety of brands purporting to be for different crops, and the requests of the

farmers were thus fulfilled. To be sure, many of these mixtures for special crops came from the same pile; and, likewise, there was a generous variety of analyses in brands recommended for the same crop.

In estimating the fertilizer needs of different crops the manufacturer has taken advantage of such information as was readily accessible, but sufficiently definite knowledge has not been available to enable him to proceed with any considerable degree of intelligence.

When fertilizers are inexpensive, or their cost is a minor consideration, as in the case of the market gardener to whom the rapidity of growth of his crops and the labor expense are of more vital importance than the cost of fertilizer, there is no hesitation about using more fertilizer than is actually needed. Used under such conditions, there could be quite a wide divergence in the analyses of fertilizers without any noticeable differences in the growth of the crop, and there would be no necessity for very careful adaptation of analyses to crops. In most circumstances, however, the ordinary farmer desires to apply only the least possible amount of fertilizer required by the immediate crop, and to avoid especially any excesses which are subject to loss.

There is no doubt that the growth response to fertilizer constituents differs widely. One has only to observe, for example, that, under identical conditions, carrots are independent of an application of acid phosphate, whereas turnips can make practically no growth without it.

It appears that farm crops must be grouped in accordance with their response to each of the fertilizer ingredients before they can be fed intelligently. Because this is a difficult and time-consuming task is not a good reason for failure to undertake it. A quite inaccurate grouping is justifiable in the beginning as a basis for modification and correction.

Such attempt as will be made in the present paper to divide some of the crops into three groups based on their relative growth response to individual applications of nitrate of soda, acid phosphate, and muriate or sulfate of potash may be justified only as an incentive to further work along this line.

At the Rhode Island station it has been rather customary to grow a number of different kinds of crops for one year crosswise of plats designed primarily to determine the effect of different applications to the soil, and in the following year to grow them lengthwise of the same plats. This has given information not only of the different response exhibited by the crops, but also concerning the effect of the plants grown one year on those planted the following season. After the two years it was, of course, necessary to devote two or three seasons to uniform cropping and thoro tilling in an attempt to make the soil sufficiently homogeneous so that the process might be repeated.

By adopting as standards for comparison certain crops to be included each year when a number of others are grown, interpolations of the different crops may be made in accordance with the indications furnished by the results obtained from time to time.

The relative growth response to a constituent of a fertilizer has usually been measured by a percentage comparison of the crop weights obtained with an optimum fertilizer to those obtained where a given fertilizer constituent has been omitted. Different combinations of nitrate of soda, acid phosphate, and sulfate or muriate of potash have been used most generally for this purpose, as in the ordinary so-called field soil test.

It should be recognized clearly that these constituents may have effects other than those attributable to their nutritive values, but they are, nevertheless, prominent constituents of fertilizers, and it is desired, therefore, to know their influence on the growth of different crops. It is understood, however, that in experiments of this kind an attempt is made to confine the effects of the constituents to the nutrients, nitrogen, phosphorus, and potassium. All other nutrients must be supplied in optimal amounts in the basal fertilizer which is common to all the plats. In brief, every other controllable factor must be made as nearly optimum as possible for the several kinds of plants in the comparison.

In any one year, even in the same locality, the weather conditions will be more favorable to some of the crops than to others, but in a series of years the advantages may be fairly evenly distributed. It is to be expected, even aside from the influence of the soil, that the results obtained in one locality may differ from those secured in another. Should this be the case, it would only show that, independent of the soil, a mixture suited to a crop in one locality might need modification for the same crop when grown in another locality.

Frequently there are economic reasons for growing a certain crop for which soil and climatic conditions are somewhat unsuitable, and where necessarily the response to fertilization would be less than in more favorable localities. Nevertheless, the response of the crop to fertilization under those same climatic conditions is what the farmer desires to know.

That crop which is increased most by the use of a fertilizer chemical is the one which may be said to have the highest needs for the fertilizer nutrient which the chemical contains. This may be the maximum increase either because the particular crop is a poor forager when the fertilizer ingredient is absent, a prolific yielder when it is applied, or

for both reasons. Conversely the minimum increase would result with that crop which is the best forager, but the smallest yielder even as a result of the addition of a fertilizer ingredient.

Crops might be classified as follows:

A. Good foragers, and small yielders even when fed;
B. Good foragers, and large yielders when fed;
C. Poor foragers, and small yielders when fed; and
D. Poor foragers, and large yielders when fed.

Class A would be quite independent of fertilizers, classes B and C intermediate in this respect, and class D would return the largest increase from the use of fertilizers.

For any fertilizer constituent groups 1, 2, and 3, respectively, may be adopted to comprise crops showing low, medium, and high response to its application. In the accompanying table a tentative attempt has been made to thus grade twenty-one crops, more as an illustration of a system for finally arriving at the fertilizer analyses adapted to different crops than with the expectation that the grading will prove to be accurate when subjected to further investigation. The present data for the different ingredients decrease in value in the following order: Phosphorus, potassium, nitrogen. The writer hopes it will be kept distinctly in mind that in certain cases there are scarcely any experimental data in existence suitable for the purpose under discussion. However, our conservatism has been overcome by the hope that investigators will be stimulated to secure information that is more reliable.

In Table 1 the crops are arranged in three groups in an increasing series according to their response to the application of, first, nitrogen; second, phosphorus; and third, potassium, the order in which these elements are arranged in the designation of a northern fertilizer. Turnips, for example, are placed in Group 2, or the medium group in relation to certain other crops, so far as their relative response to nitrogen is concerned; in Group 3 because of their high response to phosphorus; and in Group 1 with those crops which exhibit low response to potassium. Based upon this grouping, the response relation of turnips for the respective nutrients may be expressed as 2: 3: 1.

Now, it is obvious that this relation may differ materially from that expressing the relative amounts required, in order that the average crop needs for each ingredient may be supplied within economical limits. This relation will, of course, differ with the soil, and with the cost of the fertilizer ingredients. We will accept the suggestion made previously in this paper that for purposes of illustration 2:3:2 be adopted for this relation.

TABLE 1.—*Tentative arrangement of twenty-one crops into three groups in accordance with their increasing response to fertilizer elements.*

Group.	Increasing nitrogen response.	Increasing phosphorus response.	Increasing potassium response.	Relation of ammonia, available phosphoric acid, and soluble potash in fertilizer adapted to crop in preceding column.
1	Rye	Carrot	Corn	2 : 6 : 2 (3 : 9 : 3)
	Bean	Buckwheat	Rye	2 : 6 : 2 (3 : 9 : 3)
	Corn	Millet	Cabbage	2 : 9 : 2 (3 : 12 : 3)
	Cucumber	Oat	Turnip	4 : 9 : 2
	Cabbage	Pea	Bean	2 : 6 : 2 (3 : 9 : 3)
	Pea	Bean	Oat	4 : 6 : 2 (6 : 9 : 3)
	Potato	Tomato	Pea	2 : 6 : 2 (3 : 9 : 3)
2	Wheat	Corn	Millet	6 : 6 : 4
	Sunflower	Potato	Wheat	4 : 6 : 4
	Turnip	Rye	Buckwheat	6 : 6 : 4
	Tomato	Wheat	Carrot	4 : 6 : 4
	Beet	Sunflower	Potato	2 : 6 : 4 (3 : 9 : 6)
	Carrot	Barley	Tomato	4 : 6 : 4
	Oat	Lettuce	Barley	6 : 6 : 4
3	Millet	Cabbage	Squash	6 : 9 : 6 (4 : 6 : 4)
	Parsnip	Beet	Sunflower	4 : 6 : 6
	Buckwheat	Cucumber	Beet	4 : 9 : 6
	Lettuce	Onion	Onion	6 : 9 : 6 (4 : 6 : 4)
	Barley	Parsnip	Parsnip	6 : 9 : 6 (4 : 6 : 4)
	Squash	Squash	Lettuce	6 : 6 : 6
	Onion	Turnip	Cucumber	2 : 9 : 6

For any crop, therefore, which exhibits medium response to the application of each of the three fertilizer elements, namely, which is in the second group in each case, the 2:3:2 relation would be appropriate. According to the table wheat is such a crop; and to derive a fertilizer analysis for wheat each figure of the relation may be simply multiplied by the group number, 2, with the result that 4:6:4 is the wheat fertilizer.

To decide on a fertilizer for a crop which does not in all cases give this medium response, as, for example, the turnip crop which, as was stated, is in groups 2, 3, and 1, respectively, the average relation 2:3:2 would be modified by multiplying each figure by the respective group number in which turnips are placed; that is, 2×2, 3×3, and 2×1. This would result in a 4:9:2 fertilizer for turnips.

By this method the fertilizer analysis for each of the twenty-one crops in the table has been derived. In the case of phosphorus, 2 was used as the multiplier for both groups 1 and 2, because the relation for this element would be quite unusual to our conception if the smallest

factor were used. Even with this exception it happens that ten different brands were required for the twenty-one crops.

With our present inadequate knowledge there is no justification for so many brands, and it remains to be seen whether further research will ever increase our knowledge to the point where such detailed attention to analyses for different crops will be reasonable.

This will depend to a considerable degree upon the relation of the cost of fertilizer to the profits of production. The abnormal war prices of potassium, for example, stimulated a keener inquiry of the necessities of different crops for this element than had ever been manifested previously.

If further investigation leads to an accurate grouping of agricultural crops in accordance with their relative response to each of the fertilizer nutrients, it seems not too much to expect that a correlation will be found between the metabolic changes accompanying the formation of the proximate constituents of plants and the plant-food ingredients which are in some way necessary to those changes.

AGRONOMIC AFFAIRS.

MINUTES OF THE ANNUAL MEETING.

Following are the minutes of the fourteenth annual meeting of the American Society of Agronomy, held at New Orleans, La., November 7 and 8, 1921.

Morning Session, Monday, November 7th, 1921.

The session was called to order at 9:30 a. m. by President Chas. A. Mooers, agronomist and vice-director of the Tennessee Agricultural Experiment Station, in Room H, Association of Commerce Building. Forty-two members were present. The session was devoted to a symposium on nitrogen in its relation to soils and crops and was under the direction of Dr. J. G. Lipman of the New Jersey Agricultural Experiment Station. The following papers were presented:

The Formation and Movement of Nitrates, Dr. J. A. Bizzell, Cornell University, Ithaca, N. Y.

Nitrogen Gains and Losses, Dr. F. E. Bear, Ohio State University, Columbus, Ohio.

Types of Farming, Prof. C. G. Williams, Ohio Agricultural Experiment Station, Wooster, Ohio.

Lime and Other Amendments, Dr. W. H. MacIntire, Tennessee Agricultural Experiment Station, Knoxville, Tenn.

Agricultural and Commercial Values of Nitrogenous Plant Foods, Prof. A. W. Blair, New Jersey Agricultural Experiment Station, New Brunswick, N. J. (Read by the Secretary.)

President Mooers announced the foll[illegible] [illegible]lutions *Committee*, Prof. L. E. Call, Pr[illegible] [illegible]ittee, Dr. J. R. Fain, Dr. George F. Freema[illegible]

AFTERNOON SESSION, MONDAY, NOVEMBER 7TH, 1921.

Meeting was called to order by President Mooers at 2:00 p. m. There was an attendance of forty-four.

The following papers were presented, completing the symposium on nitrogen.

A Glance at the Present and Future Supply of Fertilizer Nitrogen, Director S. B. Haskell, Massachusetts Agricultural Experiment Station, Amherst, Mass.

Green Manures, Prof. M. J. Funchess, Alabama Agricultural Experiment Station, Auburn, Ala.

The Salt Requirements of Agricultural Plants. Dr. A. G. McCall, Maryland Agricultural Experiment Station, College Park, Md.

The annual business meeting was then held. The minutes of the last annual meeting were read and approved. The Secretary's report and the Treasurer's report were read by the Secretary-Treasurer and accepted. These reports follow:

REPORT OF THE SECRETARY.

I beg to submit herewith the Secretary's report.

Since taking over the duties of Secretary of the Society I have been attempting, first of all, to collect as many of the outstanding dues as possible and also to increase the membership of the Society. In the former effort, I have been materially aided by Mr. Warburton, our editor, and by our combined efforts we have succeeded in collecting many of the outstanding dues and subscriptions and have reinstated a large proportion of lapsed members. On January 1, there were 76 lapsed members. Of these, 28 have been reinstated and 12 have resigned. Of the unpaid subscriptions only 10 have not been settled for.

In the effort to increase the membership I asked assistance from various members of the Society located at our agricultural institutions and I have received the most cordial support in every case. I wish to note particularly the aid given in increasing the membership of the Society by Prof. J. H. Parker of Kansas, Dr. J. O. Morgan of Texas, Prof. A. B. Beaumont of Massachusetts, Prof. F. D. Gardner of Pennsylvania, and Mr. G. W. Musgrave of New Jersey. Many others have aided by sending in one or more new members. If it were possible for a representative in each state to be chosen who could secure as large a number of new members as Professor Parker has in Kansas, we could easily double the membership of our Society. Kansas has stood first in membership and I hope during the coming year that we will be able to increase, to a large extent, our membership in other States.

We have received 152 new members into the Society and 24 new subscriptions, giving us at the present time, a total membership of 666 and a total subscription list of 141.

At the present time there are still 74 members who have not paid their 1921 dues and 43 subscriptions unpaid. Three notices have been sent to the members and a further effort will be made before the first of the year so that none may be dropped from membership. The subscriptions will undoubtedly very largely be paid. Many of them come thru agencies and are paid later.

The [illegible] meeting of the Society held in Chicago [illegible] a success in every way; a most interesting program was given. Since that meeting the Executive Council has voted for affiliation with the A. A. A. S., which has been accomplished, and it is hoped that we may arrange as successful a winter meeting at Toronto this winter. Your Secretary was appointed *ad interim* representative of the Society on the Council of the A. A. A. S. and an appointment should be made to this position at this meeting.

Announcements of this meeting at New Orleans were sent to the entire membership on return post cards and we have receiv d somewhat over 300 cards in reply, 263 replying that they could not attend and cards from 39 announcing that they expected to attend.

Comments have been offered regarding our place of meeting in correspondence which your Secretary has had with individual members and it has been suggested that some centrally located place would permit a larger attendance of members. The suggestion has been offered that a meeting be held during the summer when experimental work in agronomy may be inspected. Director Haskell has suggested the holding of fertility schools at various institutions, a very fine suggestion which will be taken up later under new business. Your Secretary would urge that some definite action be taken regarding the place of meeting of the Agronomy Society for next year.

A nominating committee for officers was appointed by your President and ballots have been sent out from the Secretary's office and a large number returned. They are here to be counted by the committee and report made to you of the election of officers. The Executive Committee decided to sound out the membership of the Society regarding the desirability of increasing the dues and the ballot for officers included a second ballot which called for a vote on increasing the dues to $5.00 with the idea of enlarging and improving the JOURNAL. This ballot will also be counted by the committee. In this respect your Secretary would like to suggest that in his judgment the JOURNAL may be considerably increased in size if advertising were permitted in it and he sees no reason why a rather considerable amount of advertising material could not be secured. He would urge consideration of this in connection with the matter of increasing the dues of the Society. There is no question but that the JOURNAL of the Society is its advertisement and while we have been doing as well as we could with the amount of money available from dues and subscriptions, we could increase the membership of the Society and also increase the income by having a larger and better JOURNAL. It would seem desirable to make the editor chairman of a special committee to consider ways and means of increasing our income from the JOURNAL and of enlarging and improving the same and your Secretary would urge the creation of such a committee, this committee to consider the advisability of including advertising material.

Your editor has written that he is unable to file his report at this time but has requested that he be permitted to publish his report in the JOURNAL. This request should, of course, be granted. It is intended to publish also the President's address and certain of the papers presented at this meeting, if not all. Publication will also be made of the abstracts of papers presented here in *Science*, and your Secretary would urge that abstracts of all papers be placed in his hands before this meeting adjourns.

In conclusion, your Secretary ive suggestions to offer regarding increases in membership, report the same to him and any who are willing to secure members for the Society will be supplied with necessary blanks and other materials. We would urge, in this connection, the desirability of the establishment of local sections at different institutions, as several of these are now in operation and proving highly successful. This is one of the best means of increasing our membership and of getting our students and younger faculty members in touch with the Society. If we do not have a committee on local sections your Secretary would urge the appointment of a committee at this time.

Thanking all members of the Society who have so cordially supported our office during the past year in all the duties of the office, this report is respectfully submitted.

P. E. Brown, *Secretary.*

REPORT OF THE TREASURER.

I beg leave to present herewith, the report of the Treasurer for the year, November, 1920, to November, 1921.

Receipts.

Balance from Secretary Carrier	$ 200.08
Dues 1920 and previous years	118.50
Dues 1921	1,222.95
Dues, new members, 1921	446.50
Back numbers of the Journal sold	264.27
Reprints sold	120.14
Subscriptions 1920 and preceding year	325.04
Subscriptions, new, 1921	60.05
Total receipts	$2,757.53

Disbursements.

Cost of printing Journal, New Era Printing Co., and Maurice-Joyce Engraving Co.	$1 719.91
Miscellaneous expenses (stationery, stamps, printing, exchange, and telegrams)	154.48
Total expenses	$1,874.39
Balance on hand	$ 883.14

Respectfully submitted,

P. E. Brown, *Treasurer.*

MISCELLANEOUS REPORTS.

C. W. Warburton, being unable to attend, did not submit his editor's report but it was understood that he would publish it in the Journal of the Society.

Dr. C. V. Piper reported for the Committee on Terminology with an oral report, promising to submit a written report at a later date.

Dr. R. A. Oakley made no report for the Committee on Varietal Standardization.

Prof. L. E. Call made an oral report for the Committee on Teaching Agronomy, calling attention to the fact that the symposium on teaching crops and soils courses prepared as a part of the program of the annual meeting really constituted the report of the Committee.

REPORT OF COMMITTEE ON COOPERATION WITH NATIONAL RESEARCH COUNCIL.

Dr. C. V. Piper reported for the Committee on Cooperation with the National Research Council. This report was also made orally and a written report was to be filed later. The Committee recommended that the fertilizer committee of the National Research Council and the committee on salt requirements of agricultural plants be sponsored by the American Society of Agronomy, that the projects outlined by these committees be taken over by the Society, and that further projects be developed by the Committee on Cooperation and put into operation upon receiving the approval of the Executive Committee.

Dr. Piper reported three projects:

1. To assist in publishing the JOURNAL.
2. Better cooperation among agronomy workers, with an appropriation of $10,000.
3. Pasture project.

The first two are paper projects as yet.

The projects of the fertilizer committee include the preparation of monographs on lime and on the genesis of soils and the establishment of a soils research institute, all of which are paper projects, and the work on salt requirement of agricultural plants which has been carried on to some extent under the direction of a special committee.

REPORT OF COMMITTEE ON TOPOGRAPHIC SURVEYS.

The committee report on topographic surveys prepared by Dr. E. O. Fippin was read by the Secretary and adopted. The report follows:

The agronomists of the United States recognize the fundamental need of maps of the States which shall not only represent the geography of the country, but also present its physical features in a manner that will serve as a guide to and a base for the development and practical use of the resources of the country.

They recognize in the topographic maps that have already been prepared of extensive sections of the country by the Federal Government with some financial assistance from the different States, the best type of general maps for presenting the geography and relief features of the country, for the representation of scientific data depends on geographic and relief features.

In addition to their general interest in the extension of maps of this type over the entire territory of the States, the agronomists of the country are particularly concerned to have maps of this type as the base for the survey and representation of the soils of the country, in order to make known the soil and agricultural conditions and to facilitate the development of the land resources.

Therefore, the members of the American Society of Agronomy assembled in convention in New Orleans, this 7th day of November, 1921, endorse the

policy of pushing to the earliest practicable completion the topographic survey of the United States, thru the cooperation of Federal and State funds to that end, along the lines of House Bill 5230 and they urge upon Congress and the several States concerted support of measures like the topographic survey and the soil survey as basic investigations leading to the development of the resources of the country to the benefit of all its people.

A. R. WHITSON,
B. W. KILGORE,
hairman.

REPORT OF ..

The Auditing Committee submitted their report which was accepted and approved:

Your Auditing Committee beg leave to state that they have examined the books, checks and vouchers of the Treasurer and find the same to be correct.

J. R. FAIN,
GEO. E. FREEMAN,
Committee.

REPORT OF NOMINATING COMMITTEE.

The Nominating Committee, consisting of Dr. C. R. Ball and Dr. C. V. Piper, reported that ballots for officers of the Society had been sent to the entire membership and 321 ballots were returned to the Secretary. These ballots had been counted with the following results:

President, Dr. T. L. Lyon, 301.
First Vice-President, D. E. Stephens, 306.
Second Vice-President, A. B. Conner, 304.
Secretary-Treasurer, P. E. Brown, 320.

A letter from Dr. Lyon stated that he could not accept if elected and the Nominating Committee then placed the name of Prof. L. E. Call in nomination for President. Upon motion which was duly seconded and carried, Professor Call was unanimously elected president of the Society for the ensuing year. On being called upon, Professor Call responded in a timely talk urging upon all members the desirability of aiding in the work of the Society, supporting it in all its activities, and especially asking aid in increasing the membership.

AFFILIATION WITH ASSOCIATION FOR ADVANCEMENT OF SCIENCE.

President Mooers reported the Society as having affiliated with the American Association for the Advancement of Science and that upon the basis of number of Fellows in the Association who were members of the Society, it is entitled to one representative on the Council. The Secretary had been acting as *ad interim* representative.

Upon motion which was seconded and carried, Prof. C. A. Mooers was elected representative on the Council of the A. A. A. S.

COOPERATION WITH NATIONAL RESEARCH COUNCIL.

Dr. C. F. Marbut of the Bureau of Soils was then elected by unanimous ballot to the committee on cooperation with the National Research Council for a five-year term, filling the vacancy left by the completion of Professor Call's term.

AMENDMENTS TO CONSTITUTION.

Director S. B. Haskell presented the following amendments [illegible] the Constitution [illegible] the Society which could [illegible] been sent to the membership. It was underst[illegible] be held [illegible] until the next annual meeting for definite action.

To replace Articles VI and VII of the present constitution by the following:

Article VI. The officers shall consist of a president, an executive committee of five, and a secretary-treasurer. The president and secretary-treasurer shall be members ex officio of the executive committee.

Article VII. The duties of these officers shall be those usually pertaining to their respective offices. The terms of office shall be as follows:

President, one year.
Executive committee, five years, with one member retiring annually.
Secretary-treasurer, one year, or until his successor is appointed.

The president and members of the executive committee shall be elected by ballot. The secretary-treasurer shall be appointed by the executive committee.

ANNUAL DUES.

The Secretary reported results secured on the ballot submitted to the membership of the Society regarding increase in dues. Three hundred and twenty ballots were returned with the following results:

Opposed to increasing the dues to $5.00, 175.
In favor of increasing the dues to $5.00, 145.
Number who will resign if the dues are raised, 42.
Number who will not resign if the dues are raised, 232.

The discussion of this report was then entered upon and the motion was made that the dues be increased to $4.00. This motion was lost, it being considered that the majority of the Society, according to the ballots, were opposed to any increase in dues.

OTHER BUSINESS.

The matter of advertising in the JOURNAL was left to the executive committee with power to act.

A discussion of meetings, annual and special, and the holding of fertility schools was taken up. These matters were also referred to the executive committee.

President Mooers presented the proposition of the Agronomy Section of the Southern Agricultural Workers to affiliate with the Society. As no provisions of the Constitution provide for such affiliation, it was moved and carried that the matter be referred to the executive committee with the suggestion that the Constitution be amended to provide for such affiliation.

The recommendation of the Committee on Cooperation with the National Research Council was presented by Dr. Piper and it was moved and carried that the committee on cooperation be given power to assimilate the various agronomy projects of the Council and bring them under the jurisdiction of the American Society of Agronomy.

The recommendation was also approved that the committee on cooperation prepare and put into operation such other projects as they might see fit, securing the approval of the executive committee.

EVENING SESSION, NOVEMBER 7, 1921.

The evening session was a joint meeting of the American Society of Agronomy and the Society for the Promotion of Agricultural Science. A joint dinner was held at the Louisiane Cafe, arrangements having been made by Prof. A. F. Kidder. Following the dinner the meeting was called to order by Dr. C. R. Ball and the annual addresses of the retiring presidents were given as follows:

The Agronomic Placement of Varieties, Prof. C. A. Mooers, Agricultural Experiment Station, Knoxville, Tenn., President of the American Society of Agronomy.

The Relative Growth Response of Crops to Each Fertilizer Ingredient, Dr. Burt L. Hartwell, Agricultural Experiment Station, Kingston, R. I., President of the Society for the Promotion of Agricultural Science.

A third paper was then presented by Dr. E. B. Forbes entitled, The Mineral Metabolism of the Milch Cow.

About 50 were present.

MORNING SESSION, TUESDAY, NOVEMBER 8, 1921.

This session was called to order at 9:00 a. m. by President Mooers and the program consisting of a symposium on teaching crops and soils courses was presented under the direction of Prof. L. E. Call of Manhattan, Kan. The following papers were presented:

Some of the Teaching Problems of the Southern Agronomist, Dr. J. R. Fain, Georgia State College, Athens, Ga.

Progress in Standardizing the Elementary Courses in Soils, Prof. M. F. Miller, University of Missouri, Columbia, Mo.

A Plea for Experimental Work on Methods in Crops and Soils Teaching, Director S. B. Haskell, Massachusetts Agricultural College, Amherst, Mass.

What Should Constitute the Recitation Work of a Five-Hour Course in Elementary Farm Crops, Dr. W. C. Etheridge, University of Missouri, Columbia, Mo.

In addition to these papers, Prof. L. E. Call reported briefly on the conference of crops teachers at Urbana.

Dr. W. R. Hendrix spoke briefly for the committee on laboratory work in farm crops and Prof. S. C. Salmon outlined the work of the committee on intercollegiate grain judging contests.

A discussion of the papers was led by Prof. L. E. Call with a number of members participating. The discussion centered very largely about the report by Dr. Etheridge on a five-hour course in elementary farm crops. A copy of

this report is submitted separately. (To be printed with other papers presented at this session. Ed.)

The matter of a National Students' organization in agronomy was presented by Dr. Etheridge and it was moved and carried that a committee of three be appointed to plan for a national organization.

AFTERNOON SESSION, TUESDAY, NOVEMBER 8, 1921.

This session was called to order by President-elect Call at 2:00 p. m. The following papers were presented:

The Terminology of the Subdivisions of Agriculture and Some of the Broader Factors Relating to Plant Production, Dr. C. V. Piper, U. S. Dept. of Agriculture, Washington, D. C.

The Influence of Fertilizers on the Yield and Maturity of Soy Beans, Prof. Geo. L. Schuster, Delaware Agricultural Experiment Station, Newark, Del.

A New Muck Soil Problem and Its Solution, Prof. M. E. Sherwin, North Carolina State College, West Raleigh, N. C.

Soil Types as a Basis for Soil Investigations, Dr. P. E. Brown, Iowa Agricultural Experiment Station, Ames, Iowa.

Potassium-Nitrogen Ratio of Red Clover as Influenced by Potassic Fertilizers. Dr. Paul Emerson, Iowa Agricultural Experiment Station, Ames, Iowa (read by the Secretary).

In addition to these papers Prof. J. C. Pridmore presented the report from Prof. L. E. Rast on the Control of Cotton Diseases by the Use of Potash Fertilizers.

Prof. S. C. Salmon reported for Prof. Wiancko on the Standardization of Field Experiments and it was moved and carried that this committee be retained with the addition of two new members and a further report be made at the next annual meeting. The report of this committee is filed separately.

Prof. C. F. Marbut's paper on Our Inventory of Soil Nitrogen was presented by the Secretary.

Prof. S. C. Salmon reported for the committee on Intercollegiate Grain Judging Contests and in accordance with the motion which was duly carried, this report will be multigraphed and sent to instructors in all agricultural institutions and the committee will be continued with power to take such action as they may see fit in regard to the holding of contests next year.

Prof. L. E. Call then reported for the committee on resolutions as follows:

Resolved: That the American Society of Agronomy extends to all of those who assisted in making its 1921 meeting a success its heartiest thanks. Particularly does it appreciate the service of its retiring president, Dr. Mooers, who in a most able and efficient way has handled the business of the Society during the year just passing; of Dr. Brown, its Secretary, for the energy, ability and enthusiasm which he has put into the work; and of Dr. Lipman and Prof. Call, chairmen of the Symposium Committees, for the great care and thought given to the development of a program of outstanding value.

Resolved: That the Society extend to Mr. Warburton, retiring Editor, sincere thanks and appreciation for the services rendered so efficiently and untiringly in the past; and to Dr. Thatcher, Editor-elect, for his willingness to undertake the onerous duties of this important position.

Resolved: That the thanks of the Society be extended to the New Orleans Association of Commerce for the courtesy extended in allowing to the Society use of the assembly room.

Resolved: That the thanks of the Society be extended to Prof. A. F. Kidder for his aid in arranging for this meeting of the Society.

Resolved: That the Society go on record as favoring an active campaign for the establishment of group sections of the Society, in each of the more important soil and crop areas of the country.

Resolved: That the Society urge upon the officers of these group sections the desirability, and likewise the necessity, of so conducting the work of the section as to enable all persons interested to participate, men in Government service, in College, Extension, and Experiment Station Service, and in County service. It suggests that the columns of the JOURNAL OF AGRONOMY be used freely with this end in view.

This report was unanimously accepted.

The meeting adjourned.

P. E. BROWN, *Secretary.*

REPORT OF COMMITTEE ON STANDARDIZATION OF FIELD EXPERIMENTS.

The question of standardizing methods of conducting field experiments has been carefully studied by this Committee for several years. Information concerning the practices of the majority of the experiment station workers in this country has been collected. Wherever experiments in methods have been conducted the results have been analyzed. With the data at hand, the Committee now feels that the Society should make a start towards defining and adopting certain standards for locating, laying out and conducting the ordinary kinds of field experiments. In certain features of field experimental work there can be no question of the desirability of all workers adopting the same methods of procedure. In other features there are doubtless good reasons for variation, and considerable latitude must be allowed. The great variety of conditions under which field experimental work must be done makes it impossible, in certain respects, to lay down anything but very general rules. Nevertheless, certain guiding principles can be set down for making such work more uniform and the results more accurate.

It is not the expectation of the Committee that the adoption of certain standards at this time should preclude further investigations in methods or hinder progress in the development of better methods. It should rather stimulate further study. Whatever standards may be adopted, it should be understood that they are open to revision. The following recommendations concerning standards are offered for consideration and the Committee would suggest that they be published in the JOURNAL and studied by the members of the Society for a year before taking final action on their adoption.

RECOMMENDED STANDARDS FOR FIELD PLAT EXPERIMENTS IN SOIL FERTILITY.

Location of Experiments.—Soil fertility experiments should be located with reference to soil types. The location should be representative of the type

of soil to which the results of the experiments are to be applied. Only one type of soil should be represented in any one experiment.

Uniformity of Soil.—The uniformity of any piece of land for experimental purposes should be ascertained before beginning experiments. If the history of the land as to system of cropping and soil treatment for several years back is not known, it should be tested by a uniform system of cropping without soil treatment thru one or more years until its suitability for the purpose is established. Before soil treatment experiments are begun, representative samples of the soil and subsoil should be carefully taken for such analyses as it may be desired to have for future reference.

Topography.—For all ordinary field experiments, the land should be reasonably level and slope in one direction only; otherwise, special precautions must be taken to prevent soil washing. Each plat should be graded and slightly crowned in the middle to avoid depressions where water might stand or ice might form. This can be accomplished by plowing each plat by itself with the back furrow in the middle of the plat. Land subject to erosion must be only very slightly crowned. This grading or crowning of the plats should be done before any special soil treatments are applied.

Drainage.—When artificial drainage is required, the drains should be located so as to influence all plats alike. Where irrigation is practiced provision must be made to water all plats at the same time and at the same rate.

Size of Plats.—While the size of plats must often be governed by the number of plats required for the particular experiment and the amount of land available, twentieth-acre to tenth-acre plats will usually be found most desirable where horse and machine labor are to be used. There is seldom any advantage in larger plats. No field of any considerable area is altogether uniform. Where a large number of plats is required for the experiment, the smaller size will usually be most desirable because of unavoidable soil variations between the first and last plats of a large series and the time required for cultural operations.

Shape of Plats.—Long and narrow plats laid out crosswise of the greatest soil variation are preferable to square or short and broad plats because the latter are more likely to show important differences in natural fertility. The long, narrow plats are also most convenient in conducting cultural operations. For example, a plat 14 feet in width can be seeded by one round of a 7-foot grain drill and will accommodate four corn rows, and generally something near this width should be regarded as a minimum. Extremely narrow plats increase the difficulty of keeping fertilizer or manure treatments within the plat limits.

Marking the Plats.—The four corners of any series of plats should be marked by permanent markers set below the bottom of the plow furrow as a basis from which to measure in case individual plat stakes should be moved out of line. Markers for individual plat boundaries should be set in the turnways even with the surface of the ground so that implements will pass over them.

Frequency of Check Plats.—Uniformly treated plats thru which to compare the different treatments in the experiment should be regularly distributed thruout the series. At least every fourth plat should be such a check. Having every third plat a check is preferable since this provides a check plat on one side or the other of each differently treated plat in the experiment.

Treatment of Check Plats.—All check plats should receive a uniform soil treatment that will maintain them in a reasonable state of productiveness and make possible a normal growth of each crop in the rotation. This will provide a uniform standard of comparison thruout the duration of the experiment.

Untreated Plats.—One or more plats receiving no soil treatment whatever should be included in each series of plats employed in the experiment to show how the soil naturally behaves under the particular system of cropping to which it is subjected. In large series there should be one such untreated plat at each end and one in the middle.

Replication of Treatments.—The complete series of treatments, including check plats, should be repeated as many times as there are crops in the rotation employed. Thus, with a 4-year rotation there should be four series of plats in each of which the entire set of treatments is repeated in the same order. This provides for growing every crop in the rotation every year, subjects every crop to the same seasonal influences, and gives four differently located plats to get a fair average of the effect of each treatment on the particular soil type for each crop as well as for the rotation as a whole. When the experiment deals with a single crop, the entire series of plats should be at least duplicated on the same soil type. In general soil fertility tests, at least three crops of different classes should be used, as for example a cultivated crop, such as corn, a small grain crop, and a clover or grass crop.

Interspaces and Borders.—The plats in all soil fertility series should be separated by untreated interspaces at least three feet in width. Where corn or other cultivated crops are included in the rotation, the interspace may conveniently consist of one row planted in the middle of the space and removed at harvest time. For small grains and hay crops the interspace may be either sown the same as the plats and cut out at harvest time or it may be left unsowed and kept clean by cultivation. There should also be interspaces between the outside plats and borders.

The entire series of plats should be surrounded by regularly planted side and end border strips to be cut off at harvest time. Such borders should be at least 3 feet wide or equal to one or two hills or rows where cultivated crops are included in the rotation. Borders and division strips set with permanent grass may be substituted for cultivated borders and division strips, and may be advisable where there is danger of soil washing from one plat to the next.

Uniform Stand of Plants.—Only high quality, acclimated seed of standard variety should be used. The seed bed must be uniformly prepared and the rate and method of seeding should be such as to secure a uniform, normal stand of plants on all plats. Hill-planted crops should be planted thicker than required and then thinned to the desired stand soon after the plants are up. It is often wise to plant extra hills for transplanting to fill up gaps in the stand.

Use of Check Plats in Making Comparisons Between Differently Treated Plats.—When frequent, uniformly treated and equally distributed check plats are employed it is usually most satisfactory to assume that the difference between any two check plats is uniformly progressive and calculate a normal check yield for each intervening plat as a basis for determining the effect of the particular treatment. While this method is seldom if ever strictly accurate, it is usually better than to compare directly with the nearest check plat or with

either the average of the two nearest checks or the average of all the check plats in the series. It is therefore recommended that calculations of increases produced by treatments be based on the assumption that the difference between the two nearest check plats is uniformly progressive. Thus, if plats 1 and 4 are uniformly treated check plats and plat 1 has produced 50 bushels of corn and plat 4 has produced 53 bushels, it should be assumed that plat 2 would have produced 51 bushels and plat 3 would have produced 52 bushels, if they had received the same treatment as plats 1 and 4. Then, if plat 2 actually produced 56 bushels, the increase credited to the treatment would be 5 bushels and if plat 3 actually produced 58 bushels the increase credited to the treatment would be 6 bushels.

Cultural Operations.—All cultural operations except plowing should be conducted lengthwise of the plats to avoid all possibility of moving soil or fertilizer materials from one plat to another, except perhaps that hill-planted crops may be cross cultivated once or twice to clear out weeds, using implements that will not drag the soil. Plowing should usually be crosswise of the plats with a double or right and left hand plow, beginning at one end of the plats and turning all the furrows one way and leaving no dead-furrow. Where grass division strips are used, the plowing should be lengthwise and all plats should be plowed on the same day. The direction of turning the furrow should be alternated at successive plowings. Any one cultural operation should be performed with only one implement without change of adjustment and should be completed on the same day. Interruptions in cultural operations may cause serious differences in crop development. For this reason, in large series, two or three implements of the same make and similarly adjusted will hasten the work and avoid delays otherwise caused by weather conditions.

Determining Yields.—Yields should usually be determined by harvesting and weighing the produce of the entire plat. The produce must be uniformly dried before weighing. In case this can not be done, the moisture content should be determined and proper corrections made before recording the weights.

Recommended Standards for Field Experiments with Farm Crops.

The Seed.—All seeds used for planting shall be of known vitality and free from mixture, weed seeds, and contamination or infection by plant diseases, so far as this can reasonably be accomplished.

Except where adaptation of varieties or effects of previous environment is an essential part of an experiment, acclimated seed only shall be used. In varietal tests of corn, where crossing makes a strict observance of this rule impractical, it is recommended that seed be used that has been grown as near as possible to the locality where the test is to be conducted.

Careful efforts to identify unknown varieties introduced into experimental work should be made before publication of results and new names should not be applied except in case of necessity. New varieties should be named as soon as it is decided to release them for general use. Records of the history of all seeds used should be made and kept on file.

The Soil.—The soil for experimental plats should be as nearly as possible of the type prevailing in the area where the data from the crops grown on them are to be applied.

Where artificial drainage is required, the drains should be located so as to influence all the plats alike. Where irrigation is practiced the applications of water must be regulated and made the same for all plats.

The lay of the land and the general condition of the soil should be as uniform as possible. Slopes steep enough to wash materially must be avoided. It is important that for several years prior to its use for experimental purposes the cropping, fertilization, and tillage of the land shall have been uniform.

Good rotations accompanied by ordinary fertilization are necessary in varietal and cultural work to keep the productivity of the soil up to normal.

When a field or series of plats has been occupied by varietal or cultural tests, at least one bulk crop should intervene before it is again used for such tests.

The Plats.—As a rule, relatively long and narrow plats are to be preferred, both because of convenience in using machinery and because of greater accuracy on uneven land, in which case the plats should be laid out so that all will partake alike in the inequalities of the soil. The width of plats should be sufficient to allow for the removal of border rows, as hereinafter provided for, and to permit the most convenient use of machinery. Plats 5 feet or more in width, for small grains and forage crops, and wide enough for four rows of intertilled crops, such as corn and potatoes, are generally satisfactory. The length of plats may be determined largely by the amount and character of the land available. In general, field plats should not be smaller than one-eightieth nor larger than one-twentieth of an acre.

When, for lack of sufficient space, it becomes necessary to locate part of the plats in any particular experiment on a different piece of land, the break should always be made where a replication of varieties or treatments begins.

For rotation work and for ascertaining the effect of crops on those which follow, it is necessary to establish permanently the boundaries of each plat by setting suitable markers. For these purposes, plats should be at least 1 rod wide.

Check Plats.—Adequate replication of varieties or treatments removes the necessity of including check plats. If check plats are included for the purpose of deriving probable errors from yields, a large proportion of such plats appears to be necessary. If a check variety is used in varietal tests, it should be used on every third to every fifth plat and it should be a standard, well adapted variety.

Replication of Plats.—The number of years a test is continued, together with the number of plats devoted to any one variety or treatment and the size of the plats, relate definitely to the probable error for any particular test. When single plats of varieties or treatments are used, the probable error will average lower on tenth-acre plats than on plats of smaller size. The increase in probable error on successively smaller plats is relatively small when the decided reduction in size of plats is considered. By repeating varieties or treatments a sufficient number of times on regularly distributed plats of any size suitable to the purpose of the experiment, the probable error for the test may be reduced to any point considered necessary. For ordinary conditions, from two to five replications are recommended. Two plats of any variety or treatment continued through four years, or three plats continued through three years should be regarded as the minimum.

Removing Outside Rows.—When varieties are planted adjacent to each other, without the intervention of alleys, certain ones may affect others adversely. When plats are flanked or surrounded by alleys, it is known that the yields are increased and that all varieties are not influenced alike. To obviate these difficulties, it is recommended that two drill rows from either side of each plat in the case of small grain, and an equivalent width in the case of broadcasted grains or forage crops, and one row from either side of each plat in intertilled crops, be removed before harvest or left unharvested.

The Mechanical Operations.—Drills and planters should be carefully calibrated before seeding. A check on the stand should be secured by counting plants before tillering takes place. In the case of the larger intertilled crops, the seeding should be somewhat thicker than necessary and the stand thinned to the desired degree at an early stage of growth. In varietal tests where different varieties have different sized seeds, the rate of seeding drilled or broadcasted crops should be adjusted so as to get as nearly as possible the same stand of plants for all the varieties in the test. With hill planted crops such as corn, in which large and small varieties are included in the same test, there may need to be two or three different rates of planting certain varieties so as to insure fair comparisons.

All operations should be uniform for any one experiment. Plowing, seeding, or any one cultural operation should be begun and finished on the same day.

On plats of broadcasted crops and across the ends of plats with drilled crops, wires stretched on the ground in the proper places when the crops are quite small facilitate the accurate removal of borders.

Determining Yields.—When it is impractical to harvest and determine yields from entire plats, a minimum of six representative rod rows or square yards, or other areas of similar size, uniformly distributed within the plat, avoiding borders, may be used.

Two capable men shall be present at all times when weighings are made, with definite instructions that all weights must be checked.

In determining yields, possible differences in the moisture content of the crop should be considered and moisture determinations and proper corrections made when necessary. This is of special importance in tests with forage crops and in the case of late maturing varieties of corn.

The results of varietal tests on rich land should not be averaged with those on poor land, but should be used separately with the view of determining the adaptability of the varieties to each condition.

The Publication and Interpretation of Results.—It is recommended that sufficient data be published to permit the reader to draw independent conclusions.

In technical and semitechnical publications, it is recommended that probable error of yields for each season be given.

Odds of 31 to 1 against a difference in yield between any two varieties or treatments being due to normal variation are as low as it seems desirable to accept.

New varieties, cultural methods, or treatments materially different from those in common usage shall not be recommended for general use unless supported by at least three years of replicated and carefully conducted field experiments within the area for which the recommendations are made. This shall

not be interpreted as sanctioning such recommendations simply because they are supported by the minimum of experimental data nor as discouraging the early publication of experimental results for the benefit of technical workers.

Additions to Bibliography.

The following titles should be added to the bibliography of this subject published in the December, 1917, December, 1918, and December, 1919, issues of the Journal of the American Society of Agronomy:

Arny, A. C. Further experiments in field technic in plot tests. *In* Jour. Agr. Research, 21, no. 7, p. 483–499. 1921.

Bear, F. E., and McClure, G. M. Sampling soil plats. *In* Soil Science, 9, no. 1, p. 65–75. 1920.

Day, J. W. The relation of size, shape, and number of replications of plots to probable error in field experiments. *In* Jour. Amer. Soc. Agron., 12, no. 3, p. 100–105. 1920.

Harris, F. S., and Butt, N. I. The unreliability of short-time experiments. *In* Jour. Amer. Soc. Agron., 12, no. 5. p. 158–167. 1920.

Harris, J. A. Practical universality of field heterogeneity as a factor influencing plat yields. *In* Jour. Agr. Research, 19, no. 7, p. 279–314. 1920.

Harris, J. A., and Scofield, C. S. Permanence of differences in the plats of an experimental field. *In* Jour. Agr. Research, 20, no. 5, p. 335–356. 1920.

Kiesselbach, T. A. Experimental error in field trials. *In* Jour. Amer. Soc. Agron., 11, no. 6, p. 235–241. 1919.

Kiesselbach, T. A. Plat competition as a source of error in crop tests. *In* Jour. Amer. Soc. Agron., 11, no. 6, p. 242–247. 1919.

Schneidewind, W., Meyer, D., and Münter, F. Parcel size experiments. *In* Arb. Deut. Landw. Gesell., no. 296, p. 51. 1919. *Abs.* in Expt. Sta. Rec., 44, 214. 1920.

Sebelien, J. Modern methods for experiments with fertilizers and manures. *In* Jour. Agr. Sci., 10, no. 4, p. 415–419. 1920.

Stewart, F. C. Missing hills in potato fields: Their effect upon yield. New York State Agr. Expt. Sta. Bul. 459, p. 45–69. 1919.

Respectfully submitted,

A. T. Wiancko,
A. C. Arny,
S. C. Salmon,
Committee.

REPORT OF THE COMMITTEE ON TERMINOLOGY.

Your Committee begs to report that it has made some progress toward completing a Glossary of Agronomic Terms, tho not as much as had been hoped. With the progress of the work it becomes more and more evident that many new terms are needed, and many such will be proposed. It will be most desirable to present them first in the Journal so as to secure the benefits of criti-

cism, and if feasible the plan will be followed. Your Committee hopes that it may finish its task in the not remote future.

Respectfully,

C. V. PIPER, *Chairman*,
C. R. BALL,
H. L. SHANTZ.

REPORT OF ADVISORY BOARD OF THE AMERICAN SOCIETY OF AGRONOMY APPOINTED TO CONDUCT RELATIONS WITH THE NATIONAL RESEARCH COUNCIL.

Your Advisory Board has thus far submitted to the Division of Biology and Agriculture of the National Research Council only two projects, one asking for $1,000 per annum to assist in financing the publication of the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY; the other requesting $10,000 a year for bringing about greater efficiency in agronomic investigations through coordination and cooperation. Both projects were approved, but thus far no aid has been forthcoming, not thru any fault of the Research Council.

A third project, dealing with the pasture problem in its broadest aspect, has been approved in principle by the Division of Biology and Agriculture, and the finished project will soon be presented. This project originated outside of your Advisory Board, but as the Division of Biology and Agriculture deemed it important it was practically necessary for your Board to formulate the same, as it is primarily agronomic. The approval of the Society to this action of your Advisory Board is desired.

There are certain other Research Council projects, agronomic in nature, which originated during the war and which have been conducted by special committees. The Division of Biology and Agriculture now desires that these committees and their projects be sponsored by the American Society of Agronomy, as it desires all projects which are undertaken be backed by the scientific society directly concerned. There are two of these committees, as detailed below.

COMMITTEE ON FERTILIZERS FOR 1921–22.

J. G. LIPMAN, *Chairman*,
Agricultural Experiment Station
New Brunswick, N. J.

E. W. ALLEN,
Department of Agriculture,
Washington, D. C.

F. J. ALWAY,
University Farm,
St. Paul, Minn.

SAMUEL AVERY,
University of Nebraska,
Lincoln, Nebraska.

K. F. KELLERMAN,
Bureau of Plant Industry,
Washington, D. C.

B. E. LIVINGSTON,
Johns Hopkins University,
Baltimore, Md.

A. G. MCCALL,
University of Maryland,
College Park, Md.

A. E. WELLS,
60 Broadway,
New York, N. Y.

A. B. LAMB (liaison member, Division of Chemistry and Chemical Technology),
Harvard University,
Cambridge, Mass.

SUB-COMMITTEE ON PHYSIOLOGICAL SALT REQUIREMENTS OF PLANTS FOR 1921–22.

A. G. McCALL,
University of Maryland,
College Park, Md.

Remainder of membership not appointed yet.

COMMITTEE ON FERTILIZERS FOR 1920–21.

J. G. LIPMAN, *Chairman*,
Agricultural Experiment Station.
New Brunswick, N. J.

K. F. KELLERMAN,
Department of Agriculture,
Washington, D. C.

WILLIAM CROCKER,
Thompson Institute for Plant Research,
Yonkers, N. Y.

B. E. LIVINGSTON,
Johns Hopkins University,
Baltimore, Md.

The Committee on Fertilizers has several projects before the Research Council, as follows:

Soil Research Institute .... J. G. Lipman, *Chairman*.
Monograph on Lime .... W. H. MacIntire, *Chairman*.
Monograph of History of Soil Development, C. F. Marbut, *Chairman*.

The Sub-Committee on Physiological Salt Requirements of Plants has a single major project.

The present membership of your Advisory Board is as follows:

Robert Stewart, term of office expires December, 1925.
C. V. Piper, *Chairman*, term of office expires December, 1924.
J. G. Lipman, term of office expires December, 1923.
J. W. Gilmore, term of office expires December, 1922.
L. E. Call, term of office expires December, 1921.

The term of Prof. L. E. Call expires December, 1921, and requires action on the part of the Society.

C. V. PIPER,
Chairman.

REPORT OF THE EDITOR.

The 1921 volume of the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY has been a very satisfactory one so far as contents are concerned, but has been unsatisfactory in other ways. Insufficient funds have made necessary a restricted output, so that there has been a gradual accumulation of unpublished papers in the hands of the editor, with the result that a long interval elapses in practically every case between the date of submission of a paper and its publication. For instance, the papers presented at the special meeting of the Society in December, 1920, have not yet been published, due to the fact that sufficient other papers were on hand before that time to fill the available

space during 1921. Labor troubles in the shop where the JOURNAL is printed have caused long delays in issuance of the numbers since April, with attendant annoyances. Then, too, the editor has been engaged in work during the greater part of the year which has made the handling of copy and the prompt reading of proof difficult or practically impossible.

As to the make-up of the JOURNAL for 1921, it contains 41 papers by 41 authors, contributed from 21 States, the District of Columbia, and one of the Canadian provinces. This is a far wider distribution of source of material than has been common and goes to show that the JOURNAL is reaching a wider field. Two particularly valuable series of papers resulting from the 1920 meeting of the Society were printed during the year, one on agronomic teaching being printed in the February number and one on liming running thru the March, April, and May numbers. In addition to the technical papers, the JOURNAL has contained three book reviews, reports of seven agronomic meetings, and nearly a hundred news items.

A year ago the editor expressed his desire to be relieved from further duty. The executive committee of the Society found difficulty in inducing any one else to take up the work, so it was continued with the understanding that other arrangements would be made as soon as practicable. I am glad to say that the executive committee has now arranged to have Dr. R. W. Thatcher, who has been closely identified with the Society since its beginning and who has been a member of its editorial board for several years, to take up the editorship with the beginning of the next volume. The present editor wishes to thank the members of the Society, and particularly the editorial board of the JOURNAL and those who have contributed to its pages, for their forbearance and their words of encouragement and helpfulness, and to bespeak for the new editor the same courtesy that has been uniformly extended to him.

It seems fitting to review briefly the accomplishments of the seven years of my connection with the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY. During that time 53 numbers have been issued, containing a total of 2,488 pages. The 259 papers which have been printed have been illustrated with 58 plates and 151 text figures. In addition to the minutes of the annual meeting which have been printed each year, brief reports of 45 sectional meetings have been printed, as have 7 book reviews and 696 news items.

Respectfully submitted,

C. W. WARBURTON, *Editor.*

NOTES AND NEWS.

E. E. Barker, chief agronomist at the Porto Rico Insular Station, has resigned.

F. L. Duley has been granted a year's leave of absence from the Missouri station and will make special studies in soil acidity and plant nutrition at the Wisconsin station.

J. H. Harlan, assistant in agronomy at the New York State station, has been granted a year's leave of absence for graduate work at Cornell University.

R. C. Parker, in charge of the eastern bureau of the National Lime Association, has moved his headquarters from Riverhead, N. Y., to Springfield, Mass.

H. J. Webber, who has been associated with the Pedigree Seed Farms at Hartsville, S. C., recently, has returned to the California station as Professor of Citriculture and Director of the Citrus Experiment Station at Riverside.

TORONTO MEETING OF THE SOCIETY.

A special meeting of the American Society of Agronomy was held at Toronto, Canada, on December 29, 1921, in connection with the meeting of the American Association for the Advancement of Science. The following papers were presented:

1. Grain Grown in Combination for Grain Production. C. A. Zavitz, Ontario Agricultural College, Guelph.

2. Method of Obtaining Accuracy in Comparative Tests. R. Summerby, Macdonald College, Quebec.

3. Growing Hubam Clover in Iowa. F. S. Wilkins, Iowa State College, Ames, Iowa. (Read by P. E. Brown.)

4. Utilizing the Soil Survey. A. G. McCall, Agricultural Experiment Station, College Park, Md.

5. Physiological Considerations in Fertilizer Experiments. W. F. Gericke, University of California, Berkeley, Cal.

6. Soil Experiment Fields and their Value. P. E. Brown, Iowa State College, Ames, Iowa.

7. The Effects of Sudan Grass on the Biological Processes in the Soil. Paul Emerson and R. Fletcher, Agricultural Experiment Station, Ames, Iowa. (Read by P. E. Brown.)

8. Eradication of Citrus Canker and Safeguarding the Citrus Industry against Recurring Epidemics. K. F. Kellerman and W. T. Swingle, Bureau of Plant Industry, Washington, D. C.

9. Availability of Floats as Influenced by Incorporation of Barnyard Manure in the Soil. T. L. Lyon and H. O. Buckman, Cornell University, Ithaca, N. Y.

10. The Effect of Fertilization on the Growth of Sugar Beets on Some Michigan Muck Soils. N. M. McCool, Agricultural Experiment Station, East Lansing, Mich.

CONFERENCE OF NEW ENGLAND AGRONOMISTS.

The eighth annual conference of New England Agronomists was held at the Parker House, Boston, Mass., December 9 and 10. The following program was presented:

Friday, December 9, 7:30 p. m.

Report of annual meeting of the national society, Director S. B. Haskell.
Report of summer conference on teaching of crops, Prof. B. C. Helmick.
Discussion led by Prof. C. A. Michels.

Saturday morning, December 10.

Symposium on seed grading, certification and control:
- Visit to Federal Grain Supervisor's Office, Oliver Bldg., 8:30 a. m.
- Present Status and Needs in New England, Director S. B. Haskell.
- Seed Certification and Control Laws, Prof. M. G. Eastman.
- Potato Certification in Maine, Director W. J. Morse.
- Potato Certification in Vermont, Commissioner E. S. Brigham.
- Discussion led by Prof. G. E. Simmons.

Saturday afternoon, December 10.

Symposium on pasture and mowing problems:
- Statement of the Pasture Problem in the Northeastern States, Dean W. L. Slate.
- Present Status of Knowledge in Top-Dressing of Mowings, Prof. J. B. Abbott.
- Summary of Literature on Top-Dressing Pastures, Prof. H. Dorsey.
- Discussion led by Dean F. W. Taylor.
- Business meeting.

INDEX.

CONTENTS.

No. 1–2. JANUARY–FEBRUARY.

No. 3. MARCH.

No. 4. APRIL.

No. 5. MAY.

No. 6. SEPTEMBER.

No. 7. OCTOBER.

TABLE 1.—*Summary of comparisons between seed ears differing in some specific character.*

Seed ear character.	Reference.	Number of comparisons reported and crop years covered.							
		Total.		In favor of ears possessing designated character to the degree stated.					
				Large.		Medium.		Small.	
		Comparisons.	Crop years.	Comparisons.	Crop years.	Comparisons.	Crop years.	Comparisons.	Crop years.
Weight	(5)	16	16	15	15	..	..	1	1
	(56)	4	4	3	3	..	..	1	1
	(56, 57)	9	9	9	9	..	..	0	0
	(58)	2	11	1	4	..	..	1	7
	(66)	6	21	5	18	..	..	0	0[a]
	(89)	2	2	2	2	..	..	0	0
	Total	39	63	35	50	..	..	3	9
Length	(5)	16	16	16	16	..	..	0	0
	(11)	9	33	4	14	3	10	2	9
	(56)	4	4	4	4	..	..	0	0
	(56, 57)	9	9	6	6	..	..	3	3
	(58)	2	11	2	11	..	..	0	0
	(66)	6	20	4	16	..	..	2	4
	(90)	10	40	7	28	..	..	3	12
	Total	56	133	43	95	3	10	10	28
Circumference	(11)	9	28	1	1	4	17	4	10
	(57)	5	5	5	5	..	..	0	0
	(58)	2	11	1	4	..	.	1	7
	(66)	6	20	3	6	..	..	3	14
	Total	22	64	10	16	4	17	8	31
Shelling percentage	(5)	16	16	6	6	..	..	10	10
	(11)	1	1+	0	0	0	0	1	1+
	(56, 57)	6	6	0	0	..	..	6	6
	(57)	5	5	1	1	..	..	4	4
	(66)	6	21	2	8	..	..	4	13
	(90)	6	6	2	2	..	..	4	4
	Total	40	55+	11	17	0	0	29	38+
Number of rows	(5)	16	16	7	7	..	..	9	9
	(11)	7	20	0	0	3	3+	4	4+
	(56)	4	4	0	0	2	2	2	2
	(56, 57)	9	9	5	5	..	..	4	4
	(67)	1	1	0	0	1	1	0	0
	(75)	9	9	5	5	4	4	0	0
	(90)	13	13	2	2	4	4	7	7
	Total	59	72	19	19	14	14+	26	26+
Indentation	(11)	8	31	0[b]	0	1	6	7[c]	25
	(67)	1	1	0[b]	0	1	1	0[c]	0
	(90)	7	7	3[b]	3	..	..	4[c]	4
	Total	16	39	3[b]	3	2	7	11[c]	29

[a] One tie. [b] Rough. [c] Smooth.

various types, but these were too small to be significant in any one experiment and the conclusion has been practically unanimous that slight physical differences are of no value in determining the relative productiveness of good seed ears. For certain characters that have been studied most extensively, however, detailed results (5, 11, 56, 57, 58, 66, 67, 89, 90) are now available covering a large number of comparisons. These have been summarized in Table I without regard to the size of the differences.

Inasmuch as these data are based on comparisons between ears all of which were suitable for seed, the preponderance of evidence in certain cases seems convincing in spite of the fact that the determining differences in yield are small. There is every indication that selection on the basis of production, weight of ear in this case, is of value. Likewise it is indicated that it is preferable to obtain production by adding to the length rather than to the circumference of the ears, and that smoother, fewer-rowed ears with a lower shelling percentage than the standard show type are inclined to be the better yielders.

These indications are in accord with the results Hughes obtained from a comparison of 500 unselected ears (34). He found that the best 50, as picked by the majority of the 25 men who judged them, yielded not over 5 bushels per acre more than the bulk of the ears. He also concluded that ears that are inclined to be smooth with larger, coarser kernels and with more space between the rows than generally have been selected probably are best. They also agree with the reported results of several direct comparisons between a long smooth type and the rougher standard show type (18, 20, 51, 60, 67, 71). Hutcheson and Wolfe (39) drew their conclusions from a study of the progeny, rather than of the seed ears. Even so, they found that the relation between yield and percentage of grain, number of rows, average length of kernels, and space between rows was small.

It is possible that this superiority of the smoother, fewer-rowed ears was due to their persistence in a population selected too closely in another direction, as there is good evidence that close type selection may decrease yields (6, 54, 81). The superiority also may be inherent, or may be due to better seed condition caused by better maturity and greater freedom from disease (31). Whatever the cause, it seems evident that they were slightly better yielders, and the further considerations of quality and disease resistance appear to warrant selection toward a longer, smoother, fewer-rowed type than heretofore has been recommended.

The greater efficiency of producing a pound of grain on two ears rather than one has been noted by East (12) and is indicated by the

greater potential productiveness of the prolific varieties (73, 83, 84, 85) and the influence of ear-bearing tillers on yield (21, 60). Selection for 2-eared stalks has not always resulted in larger yields (70, 71), however, so that the evidence favors total production per plant as a sounder basis for selection than either size or number of ears.

Vigor, as measured by vegetative development, is associated with productiveness (10, 17, 19, 60, 61) and may serve as a selection index at an early period in the plant's growth (19, 55). Selection for such characters as height of plant or ear, however, produces conflicting results as regards yield (35, 52, 70, 71, 74, 82, 90), depending on climatic conditions in the different localities or seasons. This is well illustrated by Montgomery's results (61) in which plants having a 14 percent larger relative leaf area produced more under conditions of abundant moisture, but less under a limited water supply, than did the less leafy plants. Therefore, altho various plant characters may be used as an index in adapting a variety to specific conditions, the results of Ewing (17) and Montgomery (60, 61) show that they are of little value in selecting for yield within an adapted variety.

Finally, there is some evidence in favor of selecting under conditions of severe competition (49, 60, 90). These increases seem too small to warrant planting at excessive rates as a method of improvement, but sufficient to warrant the recommendation to select under conditions of uniform stand and fertility (88).

The limits of progress under mass selection in the sense of cumulative improvement are not now, and probably never will be, known. Regardless of whether these limits have been reached with our so-called improved varieties or not, the evidence shows that mass selection on the basis of production and quality, at least from the standpoint of maintaining yields, is entirely warranted.

HYBRIDIZATION.

Hybridization has a dual rôle in plant breeding. With corn, its use in securing new combinations for future selection has been common in practice, whereas investigations have been confined largely to the value of its immediate utilization in the first generation.

Following the results of Beal (1, 2) in 1878 to 1881, experiments were conducted from time to time to determine the possibilities of utilizing first-generation varietal crosses to obtain larger yields. In the experiments reported prior to 1893 (1, 2, 40, 59, 63, 64, 75), 14 of the 15 crosses tested produced increased yields. The method did not become popular, however, and was neglected until, after a lapse of some 16 years, the utilization of first-generation crosses was

again suggested by Shull (77), East (14), and Collins (8). Since then many crosses have been compared with their parents. Data on 244 tests of crosses between standard varieties that have been reported in some detail (24, 26, 28, 30, 38, 46, 65, 90) have been summarized in Table 2. These may well be taken as representative of all, as a survey of other reported crosses (3, 4, 6, 8, 9, 14, 15, 20, 25, 26, 47) does not indicate that they would materially affect the results.

TABLE 2.—*Summary of 244 comparisons between first-generation crosses and the parent varieties of corn.*

Reference.	Number of crosses.								
	Total.	Less than poorer parent.	As compared with average of parents.		Better than the better parent.				
					Total.	By the percentage stated.			
			Above.	Below.		0–5.	6–15.	16–25.	26+.
(24).......	96	4	83	13	51	14	26	9	2
(26).......	36	1	29	7	19	8	8	3	0
(28).......	2	0	2	0	0	0	0	0	0
(30).......	33	2	28	5	22	3	9	6	4
(38).......	4	0	3	1	1	0	1	0	0
(46).......	50	2	44	6	33	18	13	2	0
(65).......	10	3	3	7	3	1	2	0	0
(90).......	13	2	9	4	7	6	1	0	0
Total......	244	14	201	43	136	50	60	20	6
Percentage.	100.0	5.7	82.4	17.6	55.7	20.5	24.6	8.2	2.5

In these 244 comparisons 82.4 percent of the crosses produced more and 17.6 percent produced less than the average of the parents. This is conclusive as to the tendency of hybrid vigor to increase yields. Moreover, 136 of these crosses, or 55.7 percent, produced more than either parent. In such more or less haphazard crossing, therefore, the chances seem about equal of obtaining a cross that is or is not better than the better parent. The chances of obtaining a really advantageous cross—that is, one which will produce significant increases over the best of the local varieties for a series of years—are much less than equal. The best evidence as to the tendency of crosses to produce similar results in successive seasons is that from the Minnesota station (30). Crosses compared for a period of from two to four years each indicate that really significant increases obtained in one season, in general, may be expected in other seasons. That this is not absolute, however, is shown by the same data, and by the results at the Connecticut station (46, Table X, p. 339). As

pointed out by Jones (46), this is no more than is to be expected from combinations of varieties, which themselves vary so widely in yield in different seasons.

There appears to be a marked tendency (24, 26, 30, 46) for the largest actual yields to result from crosses between two varieties, both of which are high yielding, but which nevertheless differ considerably in type. The influence of the yield of the parents on the yield of the crosses is shown in Table 3.

TABLE 3.—*Comparison of first-generation crosses and the parent varieties.* (Compiled from Minn. Agr. Expt. Sta. Bul. 183, Tables 2, 8, and 9, p. 10, 18, and 19.)

Pistillate parent.	Yield in terms of Minnesota No. 13.		Cross exceeds Rustler yield.	Cross exceeds the average of parents.	
	Pistillate parent.	Cross.		Length of ear.	Number of rows.
	Percent.	*Percent.*	*Percent.*	*Inches.*	
FLOUR:					
Blue Soft	96.7	132.5	20.4	0.8	−1.2
FLINTS:					
Smutnose	110.8	127.6	15.5	0.6	−0.4
King Phillip	100.0	119.9	7.8	0.6	−0.4
Longfellow (NK)	100.5	119.6	7.5	0.5	−0.3
Longfellow (Bwls)	104.9	114.1	2.0	0.7	−0.9
Mercer	91.8	97.3	−14.8	0.1	−0.7
DENTS:					
Northwestern	105.9	115.7	3.6	..	..
Chowen	99.0	114.9	2.8	..	..
Rustler	112.1	112.4	0.3	0.2	0.1
Minnesota 23	96.7	110.9	− 1.2	0.3	0.2
Silver King	100.9	106.7	− 5.4	0.0	0.1
Murdock	80.3	101.6	−10.5	0.0	0.2

Table 3 also illustrates the effect of extreme differences in type in the larger increases obtained from crosses between flours or flints and dents than from crosses of dent varieties. Similar flint-dent crosses have produced large increases at the Connecticut station (26, 46), and crosses between southern dents and flints also have produced good yields (3, 4). Of the 14 crosses tested in Maryland by the United States Department of Agriculture in 1910 (24), two of the three advantageous ones were between Cross 120 and Hickory King as pistillate parents and Boone County White as staminate parent. Hickory King is an 8-rowed dent with large kernels. Cross 120 is a selection from an earlier Hickory King-Boone County cross, and has a somewhat longer, larger ear than Hickory King, but fewer rows and larger kernels than Boone County. This is interesting in view of the fact that the larger yields obtained from the flint-dent crosses

in Minnesota (30) was definitely associated with increased length and decreased number of rows, as shown in Table 3.

In the results reported by Hayes and Olson (30), in which eight of the twelve crosses produced more than the best of the thirteen parent varieties, the average increase was only 2.3 percent above this best variety. Even reciprocal crosses may differ so widely that one is advantageous, whereas the other is not (72). It obviously is as unreasonable, therefore, to condemn the utilization of first-generation crosses because they do not average more than the best local variety (49) as it is to recommend their indiscriminate use. It is evident that first-generation crosses offer possibilities for obtaining material increases in yield, but the value of each cross must be determined experimentally.

There seems to have been no direct investigation of the possibility of maintaining or increasing the yields of desirable crosses in succeeding generations. Referring to the crosses between Hickory King and Boone County compared in Maryland in 1910, Hartley notes that Cross 120, "after six years of selection and adaptation, produces somewhat less than the first-generation cross of the same parents made in 1909" (24, p. 19). One example is hardly conclusive, however, and in view of the fact that many of our present varieties were originated by hybridization followed by selection, it would seem that such an investigation might produce results of much interest.

EAR-TO-ROW BREEDING.

The ear-to-row method of corn breeding was introduced by the Illinois Agricultural Experiment Station about 1896 (32), and was accepted almost immediately at many of the experiment stations and by seedsmen and farmers. There have been various modifications of the method since its introduction, the more important of which may well be mentioned briefly.

One class of modifications had as its object a reduction in experimental error. Hunt (37) planted each ear in duplicate rows in different parts of the plat. Williams (86) used systematically distributed rows planted with uniform seed as a check on soil variation. Hopkins and his associates (33) compared only those rows that were grown in the same quarter of the breeding plat. Kyle (53) compared the yields of the individual ears thru the yield of uniform seed grown in the same hills as a standard. Discussion of these methods is unnecessary. From studies of field-plat technique, it now is well recognized that without replication such ear tests are of little or no

value, and that their reliability increases with the frequency of the checks and the number of replications. Other modifications were a method suggested by Hopkins and his associates (33) for preventing inbreeding, and the remnant system and introduction of "new-blood" ears suggested by Williams (86, 87) to insure high-yielding parentage on the staminate as well as on the pistillate side and to avoid close breeding.

Both increased (23) and decreased (50) yields following ear-to-row selection have been shown by comparing yields over two successive periods of years. Such measurement is unreliable, however, because of climatic influences (50). The more common test of progress has been to compare the yields of progenies of high-yielding ears with the yields of field selected seed. Results of such comparisons may be summarized as follows:

Hartley (22) obtained an average increase of 18 bushels per acre as a result of one year's selection.

Noll (65) reports a decrease of 4.7 bushels, and increases of 0.2, 0.3, and 6.2 bushels per acre in different tests, or an average of 0.5 bushel increase. Noll's results with crosses between high-yielding ears were no more significant, eight producing less and seven producing more than the field seed, with an average decrease of 2.4 bushels per acre.

Montgomery (60) reports increases of 9.5 bushels per acre after four years' and 7 bushels per acre after five years' continuous selection. From a single selection based on a two years' test he obtained an increase of 9 bushels per acre. Montgomery (60, 62) concluded that a single, careful selection on the performance basis followed by mass selection apparently was as efficient as continuous ear-to-row breeding. Since then Kiesselbach (49) has reported on later generations of these two methods. The average of the eighth to twelfth generations of continuous pedigree selection produced no increase over the original stock, whereas the seed that was mass selected following the single ear-to-row test produced 1.2 bushels per acre more than the original strain during the same years.

Hume (36) obtained an average increase over seven years' continuous breeding of 2.4 bushels per acre. During the last three of these years a different method of comparison showed a decrease of 0.2 bushel per acre. Hume (36) also compared the Illinois method for preventing inbreeding (33) with a more simple method involving no detasseling and found no appreciable difference between the methods, as an average for seven years.

Olson, Bull, and Hayes (66) compared ear-type selection with selection for ear type and yield, and secured an average increase for eight years of 5.6 bushels per acre due to the selection for yield. Of the eight comparisons, three showed negligible decreases and five increases, the range being from minus 0.3 to plus 21.1 bushels.

Williams and Welton (90) report the production of 20 crosses between high-yielding ears which were tested for one to three years each. Eighteen of these were better and two slightly poorer than field seed. The averages of the 3 to 4 strains from each mating produced increases in every case, ranging from 3.6 to 7.6 bushels per acre, the average increase during the eight seasons covered being 5.0 bushels per acre.

There is abundant proof from these results that altho individual progenies of high-yielding parents vary from actual decreases to considerable increases, as an average they may be expected to produce more than field selected seed. An original gain apparently has been lost in subsequent generations of close breeding (49, 60, 62). Close breeding is no essential part of the ear-to-row method, however, and may be prevented.

Finally, tho there is no evidence of cumulative improvement, the results of the Ohio station (90) indicate that an increase of about 5 bushels per acre can be secured and maintained under favorable conditions when close breeding is prevented. This increase is from the immediate progeny of high-yielding ears, and how much of it will persist in succeeding generations is not clear. The results at the Nebraska station (49, 60, 62), however, show that such a difference becomes less in succeeding generations.

It seems quite probable that the yield of an entirely unselected or unadapted variety could be improved by a few years' intelligent ear-to-row selection. However, in view of the expense, the uncertainty with which larger yields have been obtained, and the small increases secured during a series of years in the most favorable cases, so far there appears to be little to recommend ear-to-row breeding as a practical method of corn improvement.

PURE-LINE BREEDING.

The utilization of crosses between pure lines was first suggested by Shull (77, 78). East (14) and East and Hayes (15) accepted such a method as theoretically correct, but of doubtful value because of practical considerations. More recently Jones (43) has suggested that crosses between pure-line crosses be used commercially, over-

coming two of the serious practical objections, namely, the high cost and poor quality of the seed. The fundamental fact that inbreeding in corn results in a loss of vigor, which is regained when the isolated strains are again combined, is proved beyond question (13, 14, 15, 27, 28, 29, 42, 45, 49, 62, 65, 77, 78, 79, 80). Moreover, increased yields have been obtained from some combinations in every experiment reported.

In 1908 Shull obtained yields of 74.4 and 78.6 bushels per acre from the reciprocal crosses between pure lines, in comparison with 75 bushels from the two non-inbred parent varieties (78). In 1909 reciprocals of the best hybrid combination produced 98.4 and 96.1 bushels per acre, as compared with 88.1 bushels from the best non-inbred strain (79), and in 1910 he obtained 68.07 bushels per acre as an average from 7 hybrids, as against 61.52 bushels from 10 non-inbred strains (80).

The results of East and Hayes (15, 28) are conclusive as to the return to vigor following the crossing of pure lines. Inasmuch as these crosses were grown between rows of the inbred parents, however, and the reported yields of the non-inbred varieties were obtained in different seasons and, in one case, in a different locality (42, pp. 28, 57), the data have little relation to the question of obtaining larger yields by the use of pure line crosses.

Kiesselbach (49) gives the average yield of 11 pure-line crosses during three years as 53.4 bushels per acre, in comparison with 52.6 bushels from the original variety. It is unlikely that all of the crosses yielded equally, and some, therefore, probably exceeded this 0.8 bushel increase.

Of the 20 pure-line crosses tested by Noll (65) at the Pennsylvania station, 13 produced more and 7 produced less than the original variety. The 3 best crosses in 1914 produced increases of 11.5, 6.4, and 5.9 bushels per acre, and the 4 advantageous crosses in 1915 averaged 7.7 bushels per acre more than the non-inbred parent. These differences have been computed on a basis of 7,000 stalks per acre and 70 pounds of ears per bushel, the data having been reported as yields in pounds, from 50 stalks in 1914 and from 40 stalks in 1915.

Jones (42, Tables 11, 12, pp. 48, 49) reports the yields of 25 crosses between inbred strains of Leaming. These have been brought together in Table 4 in such a way as to show the parentage of the crosses. The yield of the original Leaming variety is given (42, Table 11, p. 48) as 80.8 bushels per acre. Of the 25 crosses, 14 produced more and 11 produced less than 80.8 bushels per acre. Of the

11 poor crosses, 6 had the 1-9-1-2 strain as pistillate parent, and 3 were crosses between the 1-7-1-1 and 1-7-1-2 strains which are more closely related. Moreover, all of the 8 crosses having the 1-6-1-3 strain as pistillate parent were high yielding. This is interesting as an indication of the consistent value of individual lines. Jones (42) notes that the seeds of strain 1-9 are the most poorly developed, whereas those of strain 1-6 are best, and suggests this as a possible cause of the differences.

TABLE 4.—*Yields in bushels per acre of crosses among pure-line strains of corn.*

(Compiled from 42, Tables 11, 12, p. 48, 49.)

Staminate parent strain.	Pistillate parent strain.				Average.
	1-9-1-2	1-7-1-2	1-7-1-1	1-6-1-3	
1-9-1-2.....	....	82.1	100.5	82.4	
	....	....	....	91.0	
				86.7[a]	89.8
1-7-1-2.....	59.6	....	70.9	101.0	
	66.3	....	....	106.2	
	63.0[a]			103.6[a]	79.2
1-7-1-1.....	58.0	55.9	....	112.9	
	52.5	58.4	....	99.1	
				94.8	
	55.3[a]	57.2[a]		88.1	
				98.7[a]	70.4
1-6-1-3.....	63.9	106.7	99.9	....	
	71.5	84.9	84.4	....	
			59.4	....	
	67.7[a]	95.8[a]	40.5	....	
			71.1[a]		78.2
Average......	62.0	78.4	80.8	96.3	

[a] Average.

Hayes and Garber (29) give the production of three crosses between two strains of Minnesota 13, previously inbred for three generations, as 51.4, 51.3, and 54.2 bushels per acre, in comparison with 48.9 bushels from the non-inbred stock.

In all of these experiments the crosses were at a disadvantage due to poor seed condition caused by the weakness of the pistillate parent. This factor is eliminated in double crosses, and Jones reports yields of 112 and 117 bushels of shelled grain per acre from double-crossed

seed, as against 92 bushels from the best variety so far found in Connecticut (43, 44).

The results prove that increased yields can be obtained from crosses or double crosses between pure lines. Can the same combinations be relied upon to produce yields in successive seasons that sufficiently exceed those which may be obtained by simpler methods to compensate for the expense of producing and crossing the pure lines? The evidence indicates that they can, but the number of experiments in which such crosses have been tested under strictly comparable conditions seems too small so far to warrant definite conclusions as to the practical possibilities of this method as a means of obtaining larger yields of corn.

CONCLUSION.

There is another and better reason for using pure-line methods in experimental corn breeding. Thruout these experiments certain basic principles are evident. First, selection produces larger yields as it secures better adaptation to the specific environment, or picks out the more favorable hybrid combinations. Selection inevitably results in decreased vigor and consequent yield, however, whenever it tends to the isolation of pure lines. Second, hybridization, whether between varieties or strains, results in increased vigor. Finally, there is a tendency for the largest actual yields to be produced when the best products of selection are used in hybrid combination. These principles long have been recognized. They attain a new significance, however, with the more recent Mendelian interpretation of hybrid vigor as the result of the combined effect of linked dominant growth factors (41, 48). The theoretical aspects of this interpretation in its relation to corn breeding have been discussed in detail by East and Jones (16) and by Jones (45), and such a consideration is beyond the scope of the present paper. Briefly, it permits the use of the same methods in pure-line breeding that have been partially successful with open-fertilized stocks, namely, selection, hybridization, and further selection, but all based on pure lines and controlled pollination.

There seems to be little reason for hesitating between methods founded on ever-changing hybrids of unknown constitution and methods in which definite pure lines, that can be reproduced at will, form the basis for improvement; or between the older methods that retained unfavorable recessive characters, but attempted to suppress them by blind hybridization, and pure-line methods that cause the

expression of these characters so that they may be recognized and eliminated. It is to be hoped that experiments will be undertaken to ascertain the possibilities in pure-line methods of corn breeding on a scale commensurate with the importance of the subject, and under methods that are in keeping with present knowledge, not only of genetic principles, but also of field-plat technique.

The possibility of progress under pure-line methods is largely theoretical so far, and it is entirely possible that unrecognized principles may interfere with the fulfillment of present expectations, as they have with those in the past. Nevertheless, the entire evidence from all corn-breeding investigations for the present points to pure-line methods as the only sound basis for real improvement of corn.

LITERATURE CITED.

1. BEAL, W. J. *In* Rpt. Mich. Bd. Agr. 1880, p. 287–288.
2. ——. *In* Rpt. Mich. Bd. Agr. 1881–82, p. 136.
3. BELLING, JOHN. Corn crosses. *In* Fla. Agr. Expt. Sta. Rpt. 1912, p. 127–129. 1912.
4. ——. Hybrid corn. Fla. Agr. Expt. Sta. Press Bul. 196. 1912.
5. BIGGAR, H. HOWARD. The relation of certain ear characters to yield in corn. *In* Jour. Amer. Soc. Agron., 5: 230–234. 1919.
6. BRUNSON, A. M. The first generation cross between two strains of corn bred for high and low ears. *In* Trans. Ill. Acad. Sci., 9: 87–91. 1916.
7. COLLINS, G. N. The importance of broad breeding in corn. U. S. Dept. Agr., Bur. Plant Indus. Bul. 141, p. 33–44. 1909.
8. ——. The value of first generation hybrids in corn. U. S. Dept. Agr., Bur. Plant Indus. Bul. 191. 1910.
9. ——. Increased yields of corn from hybrid seed. In U. S. Dept. Agr. Yearbook for 1910, p. 319–328. 1911.
10. CRAIG, C. E. Some correlations between physical characters of the maize plant, and between the physical characters and nitrogen content. Reference in Ewing (17, p. 75).
11. CUNNINGHAM, C. C. The relation of ear characters of corn to yield. *In* Jour. Amer. Soc Agron., 8: 188–196. 1916.
12. EAST, E. M. The relation of certain biological principles to plant breeding. Conn. Agr. Expt. Sta. Bul. 158, p. 87. 1907.
13. ——. Inbreeding in corn. *In* Conn. Agr. Expt. Sta. Rpt. for 1907, p. 419–428. 1908.
14. ——. The distinction between development and heredity in inbreeding. *In* Amer. Nat., 43: 173–181. 1909.
15. ——, and HAYES, H. K. Heterozygosis in evolution and in plant breeding. U. S. Dept. Agr., Bur. Plant Indus. Bul. 243. 1912.
16. ——, and JONES, D. F. Inbreeding and Outbreeding: Their Genetical and Sociological Significance. 277 p. Philadelphia: Lippincott Co. 1919.
17. EWING, E. C. Correlation of characters in corn. Cornell Univ. Agr. Expt. Sta. Bul. 287. 1910.

18. FUNK, EUGENE. Ten years of corn breeding. *In* Amer. Breeders' Mag., 3: 295–302. 1912.
19. GRANTHAM, A. E. The relation of the vigor of the corn plant to yield. *In* Jour. Amer. Soc. Agron., 9: 341–343. 1917.
20. ——. Report of field crops work at the Delaware Station, 1918. Del. Agr. Exp. Sta. Bul. 122, p. 10–20. 1918.
21. HARTLEY, C. P. Value of corn pollen f om suckers *vs.* from main stalks *In* Proc. Amer. Breeders' Asso., 2: 141–144. 1906.
22. ——. Progress in methods of producing higher yielding strains of corn. *In* U. S. Dept. Agr. Yearbook for 1909, p. 309–320. 1910.
23. ——. Circular letter of U. S. Dept. Agr., Office of Corn Investigations, 1914. Reference in Kiesselbach (50, p. 75).
24. ——, BROWN, E. B., KYLE, C. H., and ZOOK, L. L. Crossbreeding corn. U. S. Dept. Agr., Bur. Plant Indus. Bul. 218. 1912.
25. HARTWELL, B. L., and DAMON, S. C. Miscellaneous experiments with corn. R. I. Agr. Expt. Sta. Bul. 173, p. 9–10. 1918.
26. HAYES, H. K. Corn improvement in Connecticut. *In* Conn. Agr. Expt. Sta. Rpt. for 1913, p. 353–384. 1914.
27. ——. Normal self-fertilization in corn. *In* Jour. Amer. Soc. Agron., 10: 123–126. 1918.
28. ——, and EAST, E. M. Improvement in corn. Conn. Agr. Expt. Sta. Bul. 168. 1911.
29. ——, and GARBER, R. J. Synthetic production of high protein corn in relation to breeding. *In* Jour. Amer. Soc. Agron., 11: 309–318. 1919.
30. ——, and OLSON, P. J. First generation crosses between standard Minnesota corn varieties. Minn. Agr. Expt. Sta. Bul. 183. 1919.
31. HOLBERT, J. R., and HOFFER, G. N. Control of the root, stalk, and ear rot diseases of corn. U. S. Dept. Agr. Farmers' Bul. 1176, p. 13. 1920.
32. HOPKINS, C. G. Improvement in the chemical composition of the corn kernel. Ill. Agr. Expt. Sta. Bul. 55. 1899.
33. ——, SMITH, L. H., and EAST, E. M. Directions for the breeding of corn, including methods for the prevention of in-breeding. Ill. Agr. Expt. Sta. Bul. 100. 1905. Second edition, 1907.
34. HUGHES, H. D. An interesting seed corn experiment. *In* Iowa Agriculturist, 17: 424–425, 428. 1917.
35. HUME, A. N. Breeding experiments with cereals. *In* S. Dak. Agr. Expt. Sta. Ann. Rpt. for 1913, p. 24–31. 1913.
36. ——. Yields from two systems of corn breeding. S. Dak. Agr. Expt. Sta. Bul. 184. 1919.
37. HUNT, THOMAS F. The Cereals in America, p. 195. New York: Orange Judd Co. 1905.
38. HUTCHESON, T. B., and WOLFE, T. K. The effect of hybridization on maturity and yield in corn. Va. Agr. Expt. Sta. Tech. Bul. 18. 1917.
39. ——, ——. Relation between yield and ear characters in corn. *In* Jour. Amer. Soc. Agron., 10: 250–255. 1918.
40. INGERSOLL, C. L. Purdue Univ. 7th Ann. Rpt., p. 87. 1882.
41. JONES, D. F. Dominance of linked factor as a means of accounting for heterosis. *In* Genetics, 2: 466–479. 1917.
42. ——. The effects of inbreeding and crossbreeding on development. Conn. Agr. Expt. Sta. Bul. 207. 1918.

13. ——. Inbreeding in corn improvement. *In* Breeders' Gaz., 75: 1111-1113. 1919.
44. ——. The basis for corn betterment. *In* Wallace's Farm., 44: 2514-2515. 1919.
45. ——. Selection in self-fertilized lines as the basis for corn improvement. *In* Jour. Amer. Soc. Agron., 12: 77-100. 1920.
46. ——, HAYES, H. K., SLATE, W. L., and SOUTHWICK, B. G. Increasing the yield of corn by crossing. *In* Conn. Agr. Expt. Sta. Rpt. for 1916, p. 323-347. 1917.
47. Kansas Agr. Expt. Sta. Rpt. for 1917, p. 19, 23. 1918.
48. KEEBLE, F., and PELLOW, C. The mode of inheritance of stature and of time of flowering in peas (*Pisum sativum*). *In* Jour. Genetics, 1: 47-56. 1910.
49. KIESSELBACH, T. A. Recent developments in our knowledge concerning corn. *In* Nebr. Corn Imp. Asso. Ann. Rpt., 7: 15-42. 1916.
50. ——. Studies concerning the elimination of experimental error in comparative crop tests. Nebr. Agr. Expt. Sta. Research Bul. 13. 1918.
51. ——, and RATCLIFF, J. A. Freezing injury of seed corn. Nebr. Agr. Expt. Sta. Research Bul. 16. 1920.
52. KILLOUGH, D. T. Progress report of Substation Number 5, Temple, Texas. Tex. Agr. Expt. Sta. Bul. 215. 1917.
53. KYLE, C. H. Directions to cooperative corn breeders. U. S. Dept. Agr. Bur. Plant Indus. Pub. 564. 1910.
54. ——. Relations between yields and methods of selecting corn. Paper read before the Illinois Farm Advisers at Chicago, March 4, 1914.
55. ——. The relationship of early growth and the yield of grain in corn. *Abs. in* Jour. Amer. Soc. Agron., 8: 208. 1916.
56. LOVE, H. H. The relation of certain ear characters to yield in corn. *In* Proc. Amer. Breeders' Asso., 7: 29-40. 1911.
57. ——, and WENTZ, J. B. Correlations between ear characters and yield in corn. *In* Jour. Amer. Soc. Agron., 9: 315-322. 1917.
58. MCCALL, A. G., and WHEELER, CLARK S. Ear characters not correlated with yield in corn. *In* Jour. Amer. Soc. Agron., 5: 117-118. 1913.
59. MCCLUER, G. W. Corn crossing. Ill. Agr. Expt. Sta. Bul. 21. 1892.
60. MONTGOMERY, E. G. Experiments with corn. Nebr. Agr. Expt. Sta. Bul. 112. 1909.
61. ——. Correlation studies of corn. *In* Nebr. Agr. Expt. Sta. 24th Ann. Rpt., p. 108-159. 1911.
62. ——. Preliminary report on effect of close and broad breeding on productiveness in maize. *In* Nebr. Agr. Expt. Sta. 25th Ann. Rpt., p. 181-192. 1912.
63. MORROW, G. E., and GARDNER, F. D. Field experiments with corn, 1892. Ill. Agr. Expt. Sta. Bul. 25. 1893.
64. ——, ——. Experiments with corn. Ill. Agr. Expt. Sta. Bul. 31. 1894.
65. NOLL, C. F. Experiments with corn. Pa. Agr. Expt. Sta. Bul. 139. 1916.
66. OLSON, P. J., BULL, C. P., and HAYES, H. K. Ear type selection and yield in corn. Minn. Agr. Expt. Sta. Bul. 174. 1918.
67. Orange Judd Farmer. More McLean corn data. O. J. Farm., v. 63, no. 20, p. 1. Nov. 17, 1917.

68. PEARL, RAYMOND, and SURFACE, F. M. Experiments in breeding sweet corn. Maine Agr. Expt Sta. Bul. 183, p. 249–316. 1910.
69. PLUMB, C. S. Indian Corn Culture. Chicago: Breeders' Gazette print. 1895.
70. PRIDHAM, J. T. Report of plant breeder. *In* Rpt. Dept. Agr. N. S. Wales, 1914–15, p. 38–41. 1915.
71. ——. Report of plant breeder. *In* Rpt. Dept. Agr. N. S. Wales, 1915–16, p. 36–41. 1917.
72. RICHEY, F. D. The inequality of reciprocal corn crosses. *In* Jour. Amer. Soc. Agron., 12: 185–196. 1920.
73. RUSSELL, H. L., and MORRISON, F. B. Experiments in farming. Wis. Agr. Expt. Sta. Bul. 319, p. 11–16. 1920.
74. SANBORN, J. W. Selection of corn. Mo. State Col. Agr. Bul. 22, p. 5–6. 1886.
75. ——. Indian corn. *In* Agriculture of Maine, 33d Ann. Rpt. Maine Bd. of Agr., 1889–90, p. 78. 1890.
76. SCONCE, H. J. Scientific corn breeding. *In* Proc. Amer. Breeders' Asso., 7/8: 43–50. 1912.
77. SHULL, G. H. The composition of a field of maize. *In* Proc. Amer. Breeders' Asso., 4: 296–301. 1908.
78. ——. A pure line method of corn breeding. *In* Proc. Amer. Breeders' Asso., 5: 51–59. 1909.
79. ——. Hybridization methods in corn breeding. *In* Proc. Amer. Breeders' Asso., 6: 63–72. 1910.
80. ——. The genotypes of maize. *In* Amer. Nat., 45: 234–252. 1911.
81. SMITH, L. H. Ten generations of corn breeding. Ill. Agr. Expt. Sta. Bul. 128. 1908.
82. ——. The effect of selection upon certain physical characters of the corn plant. Ill. Agr. Expt. Sta. Bul. 132. 1909.
83. WIANCKO, A. T. The inheritance and effect of sucker production in corn. *In* Proc. Amer. Soc. Agron., 3: 51–58. 1912.
84. WILLIAMS, C. B. Economic value of corn suckers. *In* Proc. Amer. Soc. Agron., 4: 152–157. 1913.
85. ——, and ETHERIDGE, W. C. Characters of the corn plant associated with yield, and factors that influence them. *In* Proc. Amer. Breeders' Asso., 6: 237–244. 1910.
86. WILLIAMS, C. G. Pedigreed seed corn. Ohio Agr. Expt. Sta. Circ. 42. 1905.
87. ——. Corn breeding and registration. Ohio Agr. Expt. Sta. Circ. 66. 1907. Also, *In* Proc. Amer. Breeders' Asso., 3: 110–122. 1907.
88. ——. The selection of seed corn. Ohio Agr. Expt. Sta. Circ. 71. 1907.
89. ——, and WELTON, F. A. Corn judging: Studies of prominent ear characters in their relation to yield. Ohio Agr. Expt. Sta. Bul. 212. 1909.
90. ——, ——. Corn experiments. Ohio Agr. Expt. Sta. Bul. 282. 1915.

FIRST GENERATION CORN VARIETAL CROSSES.[1]

Fred Griffee.[2]

INTRODUCTION.

The increased vigor of F_1 hybrids has been frequently noted from the time of the early hybridists, Gärtner and Köelreuter, until the present. The utilization of the vigor of an F_1 cross as a means of increasing the yield of corn was suggested by Beal (1)[3] of Michigan in .1876. The plan which he suggested was to import seed of a variety from various localities and to plant mixtures of these importations. In a report made in 1878, Beal (3) outlines the method which is commonly used today for the production of F_1 hybrid corn seed where quantity is desired. Yellow Dent corn was secured from each of two different counties and the two strains planted in alternate rows. All of one strain was detasseled before its pollen was shed and seed was selected from the detasseled rows. Beal held the Darwinian conception that the value from hybridization was due to the fact that the two strains entering the cross had been exposed to different conditions.

In 1880 (4), Ingersoll of Indiana, Henry of Wisconsin, Georgeson of Texas, and Gulley of Mississippi met with Beal at Michigan. All agreed to carry on an experiment testing the value of using hybrid seed. The fact that, excepting for a brief report by Ingersoll, Beal was the only one to report indicates clearly that little enthusiasm had been aroused for this method of increasing production.

Morrow and Gardner (17, 18) in 1892 and 1893 published the results of experiments in which the F_1 hybrids were definitely compared with their parents. Renewed interest was aroused by the publications of East (8) in 1908 and Shull (19, 20) in 1908 and 1909 on the effects of inbreeding and crossbreeding in corn.

[1] Published with the approval of the Director as Paper No. 244, of the Journal Series of the Minnesota Agricultural Experiment Station. Read at the meeting of the American Society of Agronomy, Chicago, Ill., December 31, 1920.

[2] Assistant Plant Breeder, Minnesota Agricultural Experiment Station. The writer desires to express his appreciation to H. K. Hayes, Division of Agronomy and Farm Management, for assistance in the preparation of this paper.

[3] Numbers refer to Literature cited, pp. 26-27.

Shull's pure line method of breeding was based on the hypothesis that a field of corn is composed of complex hybrids. Some of these hybrids are more heterozygous than others and consequently more vigorous. He advocated the isolation of pure lines by self-fertilization. These pure lines were then to be planted in alternate rows and all of one pure line detasseled. Seed for the general field was to be selected from these detasseled rows. Such hybrid seed would produce a field of corn in which every plant was heterozygous—that is, every plant would be as vigorous or more so than the most productive plants in the original mixed strain. Preliminary reports by Shull showed that some F_1 crosses were more vigorous than the original commercial variety.

Collins (6) believed, however, that the most advantageous combination might be found without first "reducing the varieties to the verge of extinction before the cross is made." East, while accepting the correctness of Shull's method from a theoretical standpoint, was inclined to the belief that F_1 varietal crosses had greater commercial possibilities.

The studies of Collins (6, 7), reported in 1909 and 1910, added materially to our knowledge of the value of first-generation hybrids in corn. The possibility was suggested that the use of the first-generation hybrid vigor might allow the extension of corn growing beyond the present area of production. Since hybrids grown at Washington, D. C., in 1910 remained dark green and vigorous when nearly all of the parental strains were showing signs of drought, Collins concluded that first-generation hybrids may be "relatively free from the new-place effects that so seriously interfere with the spread of varieties."

Since the first introduction of the method of utilizing hybrid vigor as a means of increasing yield in corn experimental tests have been made in most of the corn states. It is only within the last few years, however, that investigators have fully appreciated the value of careful field-plot technique. Many tests did not take into consideration the value of eliminating the effect of competition that may enter when varieties are grown side by side in single-row plots. The necessity of using replicated tests in order to overcome the harmful effect of soil heterogeneity has not been generally appreciated. In some cases the cross was compared with only one parent, and in many cases the experiments were carried for a single year only. In still other cases unadapted varieties were used.

Before making a review of F_1 crosses a brief statement of the

Mendelian hypothesis which most logically explains hybrid vigor will be given.

THE MENDELIAN EXPLANATION OF HYBRID VIGOR.

Since the discovery of linkage, or the fact that factors are inherited in groups, an adequate Mendelian explanation has been proposed which accounts for the increased vigor of an F_1 cross. East and Jones (9) in "Inbreeding and Outbreeding" give an excellent review of the development of this theory.

The theory assumes that varieties, which when crossed yield an increase in produce in the first hybrid generation, possess growth factors which are not common to both, and that these factors are partially or completely dominant over their allelomorphs. Thus, a factor pair will give more than half the stimulus to growth when in the heterozygous than when in the homozygous condition. Linkage of factors in inheritance explains why all favorable growth factors can not be combined in a homozygous individual. The only way to discover the best cross is to conduct field tests over a number of years, in which the hybrids compete not only with their parents, but with the best yielding variety for the locality in which the hybrid is to be grown. The increased vigor must be sufficient to pay for the extra labor of producing hybrid seed. That F_1 corn crosses frequently do give increased yields is evident from a summary of experiments which have been made.

PREVIOUS F_1 CROSSES SUMMARIZED.

In the following summary only those crosses which have been compared with both parents have been considered. Recent studies of the Minnesota station will be discussed in some detail later.

Morrow and Gardner (17, 18) in 1892 and 1893 tested nine F_1 hybrids, of which five exceeded the better parent in yield.[4] These tests consisted of a comparison in single-row plots of adapted varieties and their F_1 crosses. (See Table I.)

Collins (7) tested sixteen crosses of widely different types at Lanham, Maryland, and twelve outyielded the better parent. He also tested ten crosses between varieties of sweet corn at Washington, D. C. Of these, seven exceeded the better parent in yield. These results were based on single plot tests.

Hayes and East (12) in 1911 reported the results of three crosses in comparison with their parents. Two of the three crosses out-

[4] In the summary of previous F_1 crosses the term "yield" refers to yield of grain.

yielded the better parent. A later report by Hayes (11) compares twenty-seven F_1 crosses with their parents. Fifteen of these crosses exceeded the better parent in yield. Adapted varieties were used for these crosses.

Hartley and others (10) conducted tests at Chico, California, and Waco, Sherman, and Corsicana, Texas. Sixteen crosses grown in California were made in Maryland and were not adapted to California conditions. Of these sixteen only four yielded an increase as compared with the better parent. In the Texas experiments adapted varieties were used and the tests were made at three stations. Results here given are averages of the three stations. Of the eleven crosses, four exceeded the better parent in yield.

Belling (5) tested a single cross in 1912. The cross yielded more than the better parent. He used one replication, but grew single-row plots.

Williams and Welton (21) used single plots and adapted varieties. They grew seven F_1 crosses, of which five exceeded the yield of the better parent.

Jones and others (15) made tests at two different stations. In all twenty-seven tests were made, in eighteen of which the F_1 cross exceeded its better parent in yield. These workers used adapted varieties, but single plots.

Kiesselbach of Nebraska (16) reports comparisons of ten crosses between late varieties. The average yield of these ten crosses was 1.97 percent less than the average of the parents. Kiesselbach also tested three crosses between early and late varieties. These averaged a 1.2 percent increase over the average of the parents.

Hutcheson and Wolfe (14) compared four F_1 crosses with their parents, one of which outyielded the better parent. These authors used adapted varieties and three replications.

These tests are summarized in Table I. In all 146 F_1 crosses have been briefly reviewed. Of these, 113 exceeded the parental average in yield of grain and 84 exceeded the better yielding parent. The percentage increase in yield over the average of the parents for the 146 F_1 crosses is 11.7.

These results certainly show that F_1 crosses on the average give increased yields as compared with normal varieties.

MINNESOTA RESULTS.

Hayes and Olson (13) summarized, in 1918, the results of a series of tests of F_1 crosses which had been carried on from 1915 to 1918, inclusive. Minnesota No. 13, which had been selected for ear type

TABLE 1.—*Summary of comparative yields of first generation crosses and parents.*

Authority.	Location.	No. crosses tested.	No. crosses exceeding better parent.	No. crosses giving decrease from better parent.	Average percent increase or decrease from better parent.	No. crosses exceeding parental average.	No. crosses giving decrease from parental average.	Average percent increase or decrease from average parent.	Method of test.
Hartley, et al, 1912 (10)	Chico, California	16	4	12	− 2.5	13	3	+ 7.7	Single rows, unadapted.
Hayes & East, 1911 (12)	Mt. Carmel, Conn., 1911	3	2	1	+ 1.8	3	3	+28.0	Single rows, unadapted.
Collins, 1910 (7)	Lanham, Md.	16	12	4	+16.6	14	2	+53.0	Widely different types, 16 hills.
Collins, 1910 (7)	Washington, D. C.	10	7	3	+25.6	8	2	+81.0	Sweet corn, single plots.
Morrow & Gardner, 1892 (17)	Champaign, Ill.	5	3	2	+ 7.0	5	0	+14.0	Adapted varieties, single plot test.
Morrow & Gardner, 1893 (18)	Champaign, Ill.	4	2	2	− 1.2	3	1	+ 7.7	Adapted varieties, single plot test.
Hayes, 1913 (11)	Mt. Carmel, Conn., 1912	19	10	9	− 3.5	16	3	+10.1	Av. one replication, adapted, single rows.
Hayes, 1913 (11)	Mt. Carmel, Conn., 1913	8	5	3	+ 5.3	5	3	+ 8.3	Single plots, 3 rows, adapted.
Hartley, et al, (10)	Texas, Sherman, Waco, Corsicana	11	4	7	− .1	10	1	+ 9.8	Av. three test in dif. places, adapted, single rows.

TABLE 1.—*Continued.*

Belling, 1912 (5)	Florida	1	1	.	+43.7	1	.	+48.0	Adapted varieties, single plots.
Jones, et el, 1916 (15)	Av. Mt. Carmel, Storrs, Conn.	9	6	3	+ 2.3	9	0	+ 8.5	Adapted varieties, single plots.
[illegible]es, et al, 1916 (15)	Av. Mt. Carmel, Storrs, Conn.	8	3	5	− 3.0	5	3	+ 3.7	Adapted varieties, single plots.
Jones, et al, 1916 (15)	Mt. Carmel, Conn.	12	9	2	+ 4.2	11	1	+16.3	Adapted varieties, single plots.
Hutcheson & Wolfe, 1917 (14)	Blacksburg, Va.	4	1	3	11.2	3	1	+ 4.3	Av. three replications adapted, 4 row plots.
Williams & Welton, 1915 (21)	Ohio	7	5	2	+ .3	7	6	+ 3.2	Adapted varieties, single plots.
Hayes & Olson, 1919 (13)	University Farm, St. Paul	11	10	1	+11.7	10	1	+14.5	Adapted var. 2–4 yrs. test in dif. lots.
Kiesselbach, 1916 (16)	Nebraska	10	..	..	..	..	..	− 1.9	Adapted var. late var.
Kiesselbach, 1916 (16)	Nebraska	3	..	..	..	..	..	+ 1.2	Adapted var. early and late var.

for a period of several years prior to the test, was used as the male parent. Five flint varieties which were adapted to central Minnesota conditions were secured and an equal number of adapted dent varieties. Arrangements were made to secure seed of these varieties from the same growers each year. The F_1 crosses of the varieties here given were tested for a period of at least two years and in some cases for the four years from 1915 to 1918, inclusive.

Four rows, each 132 feet long, were used for each plot, the two central rows only being used for the yield tests. The various F_1 crosses were planted so that each was grown between its respective parents. Two or more systematically distributed plots were used for each variety and cross.

Of the five flint-dent crosses, four gave a significantly larger yield of bushels of shelled corn per acre than the better parent and one yielded slightly less than the parental average. The average increase in yield of bushels of shelled corn per acre of the F_1 flint-dent crosses over the better parent was 12.5 percent. The five dent crosses gave an average increase of 6.7 percent in yield of bushels of shelled corn per acre as compared with the better parent. Three of the dent varieties used were, however, somewhat too late in maturity for University Farm conditions and these crosses have not been further studied.

Rustler White Dent, which matures about the same time as Minnesota No. 13, has been grown at University Farm since 1915. During the last three years Minnesota No. 13 and Rustler Dent have been grown in isolated seed plots. Selection of seed for planting has been made at maturity from vigorous stalks in perfect stand hills. During the last two years those crosses which appeared most promising for the 1915 to 1918 test have been continued. In addition, crosses between Rustler and selected eight-rowed flints have been grown. For the period 1915 to 1920, inclusive, F_1 crosses between Minnesota No. 13 and the varieties Longfellow and Rustler have been tested each year. King Phillip × Minnesota No. 13 has been tested five years. Squaw Flint × Minnesota No. 13, Rustler × Longfellow, and Rustler × King Phillip have each been tested in the 1919 and 1920 seasons. Results of these tests will be considered in a little more detail.

A cross, Northrup King's Longfellow × Minnesota No. 13, was tested for the full six-year period. (See Table 2.) Four of the six years the cross yielded more bushels of shelled corn per acre than the better parent, one year the same as the better parent, and the remaining year somewhat more than the parental average. For the average

of six years it yielded 11.7 percent more in bushels of shelled corn per acre than the better parent.

While the cross of King Phillip × Minnesota No. 13 yielded more grain than either parent for each of the first three-year tests, it yielded slightly less in the last two years. For the five-year period, however, the cross exceeded the better parent by 8.8 percent in yield of bushels of shelled corn per acre.

TABLE 2.—*Comparative Yield of First Generation Crosses and Parents, 1915 to 1920 inclusive.*

Variety.	Yield in bushels per acre.							Yield percent No. 13 as 100.	Cross minus better parent.
	1915.	1916.	1917.	1918.	1919.	1920.	Avg.		
No. 13	21.8	54.2	....	47.9	70.1	33.0	45.4	100.0	
King Phillip	25.9	53.9	....	43.8	60.9	30.3	43.0	94.7	
Cross	32.6	63.3	....	52.6	68.6	30.1	49.4	108.8	8.8
No. 13	21.8	54.2	22.9	47.9	66.0	32.3	40.9	100.0	
Longfellow (N.K.)	29.8	48.1	22.1	47.4	58.5	26.2	38.7	94.6	
Cross	42.4	52.5	22.9	57.6	63.0	35.7	45.7	111.7	11.7
No. 13	....	....	....	....	70.0	30.4	50.2	100.0	
Squaw Flint	....	....	....	....	46.1	28.4	37.3	74.3	
Cross	....	....	....	....	72.8	36.0	54.4	108.4	8.4
Rustler	....	....	....	....	68.6	33.9	51.3	100.0	
King Phillip	....	....	....	....	58.6	30.5	44.6	86.9	
Cross	....	....	....	....	70.6	37.4	54.0	105.3	5.3
Rustler	....	....	....	....	69.2	36.0	52.6	100.0	
Longfellow	....	....	....	....	60.9	25.4	43.2	82.1	
Cross	....	....	....	....	74.1	35.6	54.9	104.4	4.4
No. 13	20.2	34.1	22.1	52.1	72.5	33.0	39.0	100.0	
Rustler	25.0	42.5	22.8	53.7	72.1	33.6	41.9	107.4	
Cross	26.7	45.1	22.7	49.9	75.7	38.1	43.0	110.3	2.9

Longfellow × Rustler for 1919 and 1920 exceeded the better parent in yield of grain by 4.4 percent. King Phillip × Rustler for the same two-year period yielded an increase of 5.3 percent over the better parent.

Rustler × Minnesota No. 13 yielded 2.9 percent increase in bushels of shelled corn per acre over the better parent. These two varieties have been grown from home-grown seed and since 1918 they have been selected for yield.

The cross between the early flint variety known as Squaw Flint and Minnesota No. 13 which was tested for the 1919 and 1920 seasons is of particular interest. The cross grew nearly as tall as Minne-

sota No. 13, showed the stooling ability of the Squaw Flint, produced ears nearly as large as Minnesota No. 13, yielded more grain per acre than Minnesota No. 13, and was a week to ten days earlier in maturity than Minnesota No. 13.

CONCLUSION.

The results of the test of F_1 crosses here reviewed are conclusive evidence that under present methods of corn breeding F_1 varietal crosses are a means of obtaining increased yields.

The correctness of present methods of corn seed selection, however, is problematical. Uniformity of ear type is the usual aim of the corn breeder. The result of University Farm tests of F_1 varietal crosses showed considerable larger increases in yield of shelled corn per acre in the earlier years of the study when Minnesota No. 13 was closely selected for ear type. However, even in recent years when selection in Minnesota No. 13 for yield alone has been practiced the cross between Squaw Flint and Minnesota No. 13 has given 8.4 percent greater yield of shelled corn per acre than the higher yielding parent. Such a cross looks very promising for conditions where early maturity is a necessity.

LITERATURE CITED.

1. BEAL, W. J. Changing Seeds. *In* Mich. Bd. of Agr. Ann. Rept. 15: 206. 1876.
2. ——. Breeding Corn. *In* Mich. Bd. of Agr. Ann. Rept. 16: 56. 1877.
3. ——. The Improvement of Grains, Fruits, and Vegetables. *In* Mich. Bd. of Agr. Ann. Rept. 17: 454. 1878.
4. ——. Improving Indian Corn. *In* Mich. Bd. of Agr. Bienn. Rept. 1: 134-136. 1882.
5. BELLING, J. Hybrid Corn. Fla. Agr. Exp. Sta. Press Bul. 196. 1912.
6. COLLINS, G. N. Increased Yields of Corn from Hybrid Seed. *In* U. S. Dept. Agr. Year Book *1919*: 319-328.
7. ——. The Value of First-Generation Hybrids in Corn. U. S. Dept. Agr., Bur. Plant Indus. Bul. 191. 1910.
8. EAST, E. M. Inbreeding in Corn. *In* Conn. Agr. Exp. Sta. Ann. Rept. 31 & 32: 419-428. 1908.
9. ——, and JONES, D. F. Inbreeding and Outbreeding. 285 p. Philadelphia and London: J. B. Lippincott Company. 1919.
10. HARTLEY, C. P., BROWN, E. B., KYLE, C. H., and ZOOK, L. L. Crossbreeding Corn. U. S. Dept., Bur. Plant Indus. Bul. 218. 1912.
11. HAYES, H. K. The Corn Plant and Seed Selection. *In* Conn. Agr. Expt. Sta. Ann. Rept. 37: 353-390. 1914.
12. ——, and EAST, E. M. Improvement in Corn. *In* Conn. Agr. Expt. Sta. Bul. 168. 1911.

13. ——, and OLSON, P. J. First Generation Crosses between Standard Minnesota Corn Varieties. Minn. Agr. Expt. Sta. Tech. Bul. 183. 1919.

14. HUTCHESON, T. B. and WOLFE, T. K. The Effect of Hybridization on maturity and Yield in Corn. Va. Agr. Exp. Sta. Tech. Bul. 18. 1917.

15. JONES, D. F., HAYES, H. K., SLATE, W. L. and SOUTHWICK, B. G. Increasing the Yield of Corn by Crossing. *In* Conn. Agr. Exp. Sta. Ann. Rept. 40: 323–347. 1917.

16. KIESSELBACH, T. A. Studies concerning the elimination of experimental error in comparative crop tests. Nebr. Agr. Exp. Sta. Res. Bul. 13. 1917.

17. MORROW, G. E. and GARDNER, F. D. Field Experiments with Corn. Ill. Agr. Exp. Sta. Bul. 25. 1893.

18. ——. Experiments with Corn. Ill. Agr. Exp. Sta. Bul. 31. 1894.

19. SHULL, G. H. The Composition of a Field of Maize. *In* Amer. Breed. Assn. Ann. Rept. 4: 296–301. 1908.

20. ——. A Pure-line Method of Corn Breeding. *In* Amer. Breed. Assn. Ann. Rept. 5: 51–59. 1909.

21. WILLIAMS, C. G. and WELTON, F. A. Crossbreeding Corn. *In* Ohio Agr. Exp. Sta. Bul 282: 100–103. 1915.

EAR-TYPE SELECTION AND YIELD OF DENT CORN.[1]

T. A. KIESSELBACH.[2]

The subject assigned the writer in this symposium was at one time of greater importance in the minds of agronomists and others than it is today. In the latter part of the nineteenth century a rather arbitrary a priori doctrine for ascertaining productive excellence of the seed ear was evolved from the mistaken line of reasoning that high shelling percentage and grain yield of the seed ear was synonymous with relatively high acre production. Thru associating this belief with the evolutionary teaching that like begets like, this ear-type perfection was to be preserved thru purity of breeding and selection for uniformity. Aside from the qualities denoting soundness of the grain, with its very obvious value, practically all of the points featured in the early score cards, devised as a guide for selecting seed ears, have their origin in the above reasoning.

These new teachings aroused great interest in corn and a number of station workers and practical corn growers planned experiments to

[1] Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Read at the meeting of the American Society of Agronomy, Chicago, Ill., December 31, 1920.

[2] Agronomist, Nebraska Agricultural Experiment Station.

establish their significance. The outcome was to suggest that the physical ear characters of dent corn fall into two definite groups, those definitely nonutilitarian and those tending to be utilitarian. As an expression of progress in public sentiment, the tendency in some States has been to revise the corn score card, from time to time, attaching greater emphasis to important utilitarian considerations, such as adaptation and soundness. The other type considerations appear to be largely nonutilitarian, from the seed standpoint.

It may be observed that no score card for judging competitive ear corn exhibits has yet been devised whereby nonutilitarian considerations are entirely eliminated and may not in many close cases determine the placing of awards. The Illinois score card of 1920 and the Nebraska score card of 1918 are outstanding in their subordination of nonutilitarian considerations. The former attaches about 80 percent of a perfect score to soundness, viability, and freedom from disease. The latter gave approximately 70 percent to soundness, viability, and adaptation.

The ear characteristics which have received chief consideration by corn enthusiasts are: 1, adaptation; 2, soundness; 3, maturity; 4, size of ear; 5, trueness to type; 6, uniformity of ears; 7, uniformity of kernels; 8, shape of kernels; 9, space between kernels; 10, depth of kernels; 11, total weight of grain; 12, shelling percentage; 13, shape of ears; 14, color of cobs; 15, color of kernels; 16, character of butts and tips of ears; and 17, straightness of rows.

The essential requirements of seed corn are that it shall be sound and that it shall be well adapted to the conditions where planted. The degree of adaptation depends upon the degree of harmony between the plant requirements and its environmental growth conditions. The highest degree of adaptation is regarded as that resulting in the maximum yield of sound grain per acre. The most pronounced environmental factors correlated with the growth habits of corn plants best suited for any region are climatic. Wide hereditary differences in native corn types are found in response to variation in climate. Thus, comparing adapted Lancaster Co., Nebr., corn with adapted Kimball Co., Nebr., corn, when both were grown under favorable conditions of Lancaster County, the former ripened 18 days later, produced plants which were 40 percent taller, bore the ears 150 percent higher above the ground, had 138 percent greater leaf area per plant, and produced 100 percent greater total dry matter per plant. The ears were 123 percent heavier, and had a 10 percent higher shelling percentage. These are inherited differences, which may be

ascribed primarily to the normal climatic differences of the two regions. Comparing the climate of Lancaster County with that of Kimball County, the normal temperature of the corn-growing season is 7° F. warmer, the frost-free period is 35 days longer, and the precipitation is 13 inches, or 81 percent, higher.

Plants of such differing growth habits commonly have distinct types of grain and ear. The special adaptation is more or less reflected in the ear. Smoothness and shallowness of grain, low shelling percentage, small ear circumference, and a low number of rows of grain per ear suggest relative earliness and small vegetative growth. Rough, deep grain, high shelling percentage, large circumference, and a high number of rows on the ear are rather characteristic of late maturity and large plant growth. In a general way, in response to adaptation, the more adverse the growing conditions are for corn, the more nearly does the corn approach the small stalk, low leaf area, slender ears, and smooth, shallow kernel of flint corn. This adjustment is often spoken of as "running out" of the corn, whereas it is an actual betterment for the prevailing conditions.

The so-called utilitarian ear characteristics have significance only in so far as they are linked with inherent vegetative growth habits of the corn plant. The exact nature of these plant characters and degree to which they will reproduce themselves can not be reliably judged by a mere examination of the ear. The correctness of such judgment is greatly enhanced by a previous knowledge of the source and purity of breeding of the corn. Thus, a small, smooth, shallow-grained nubbin of Boone County White grown in Indiana might very closely resemble an average ear of Marten White Dent corn which is well adapted to the short and dry season of western Nebraska. But if the two ears were planted side by side in Indiana, the one would produce plants about twice as large and five weeks later in maturing than the other.

It apears to be an almost universal practice on the part of the corn grower to pull somewhat against the natural law of adaptation by growing corn slightly too large and late for his conditions. This is in large measure brought about by an effort to approach the ear characteristics of corn grown in the most favorable corn districts of the country. This has been especially evident in the settlement of the western and northern frontiers of the corn belt. Newcomers found that the corn which they brought with them from more favored sections assumed more and more the dwarfish characteristics of adverse conditions. They believed their corn to be running out and replaced

it from time to time with imported seed, or selected for planting the ears which most nearly approached the original characteristics. Thru experience, however, the corn grower is coming to recognize the advantage of modifying his conception of ear type to harmonize with the environment of his locality. There is no such thing as a universal best type.

It is the purpose of this paper to present a brief digest of the available published data from the various agricultural agencies, including some unpublished results at the Nebraska Agricultural Experiment Station. It was thought that by bringing the important data together in this compact form, the reader would be aided in drawing his own conclusions. The experimental data are classified largely by States or institutions, since this avoids a frequent restatement of the methods or nature of the tests.

OHIO EXPERIMENTS.

Williams and Welton (18)[3] report results from the Ohio station as follows: In a 9-year test with three varieties, tapering ears outyielded cylindrical ears 2.3 percent in grain production (68.3 against 66.8 bu.). As an average for 7 years, smooth ears of the Clarage variety yielded 2.7 percent more grain than rough ears (65.3 to 63.6 bu.). Ears with bare tips having 1.2 inches of exposed cob yielded 0.3 percent less grain than ears with well-filled tips (62.4 to 62.7 bu.) as an average for 8 years.

During 10 years the long ears (averaging 9.2 inches) of four varieties exceeded the short ears (6.8 inches) by 2 percent in grain yield (69.5 to 68.2 bu.). In a 5-year comparison of 14-rowed and 18-rowed ears the former exceeded the latter 1.7 percent (60.9 to 59.9 bu.) at Wooster and 6.4 percent (57.6 to 54.2 bu.) at Germantown.

In a 6-year comparison of Clarage corn at Wooster, ears with high percent (88.2 percent) of grain yielded 0.6 percent less than ears of low (76.4 percent) shelling percentage (64.6 to 65.1 bu.). The shelling percentage of the ears grown from the two lots was 86.1 and 80.8 percent, respectively.

The Ohio experiments suggest a possible slight advantage for the long, slender, smooth ears, altho there is no very material difference between any of the types.

McCall and Wheeler (13) have calculated the coefficients of correlation for extensive ear-to-row tests between grain yield and the

[3] Reference by number is to Literature cited, p. 48.

length, weight, circumference, and density of the seed ears (Table 1). The yield tests cover seven years, 1905 to 1911, by the Ohio Agricultural Station and four years, 1906–1909, by J. W. Cook at Forrest, Ohio. No significant correlation was discovered.

TABLE 1.—*Correlation of ear characters and yield in corn. (McCall and Wheeler data).*

Array number.	Character.	Number of variants.	Coefficient of correlation.
I	Length	476	+.0580 ± 0.296
V	do	105	+.1017 ± 0.651
II	Weight	530	−.0270 ± .0292
VI	do	104	+.0866 ± .0656
III	Circumference	530	−.0968 ± .0287
VII	do	105	+.1803 ± .0636
IV	Density	526	+.0272 ± .0293

KANSAS EXPERIMENTS.

Table 2 presents data based on extensive ear-to-row tests, reported by Cunningham (3) of the Kansas Agricultural Experiment Station. The tests cover nine varieties during six years. Altho the ears planted were all of fair length, they were divided into three groups, long, medium, and short, for which the respective grain yields were 48.2, 48.4, and 48.2 bushels per acre. Ears having 16, 18, and 20 rows yielded, respectively, 43.5, 41.4, and 39.9 bushels per acre. This is 3.6 bushels between the extremes in favor of the 16-rowed ear. The small number of rows would seem to be correlated, to some extent at least, with small ear circumference. Ears with relatively large, medium, and small circumferences yielded 47.9, 49.3, and 49.6 bushels, which is 1.7 bushels in favor of the most slender ear. Ears with shelling percentages of 88, 86, 84, and 82 percent yielded 49.6, 49.9, 49.8, and 50.8 bushels per acre, respectively. The lowest shelling percentage yielded 1.2 bushels more than the highest. The yields of very rough, medium rough, and smooth-grained ears were 49.2, 52.6, and 53.5 bushels per acre, respectively, which is 3.3 bushels more for the smooth than the rough ears. Ears with well-filled, medium-filled, and poorly filled tips yielded, respectively, 51.7, 51.8, and 51.8 bushels per acre. Poor and partially rounded butts both yielded 51.0 bushels per acre compared with 50.7 bushels for well-rounded butts. Little relation between type and yield is shown by these Kansas data, aside from suggesting superiority for the rather slender, smooth ear of low shelling percentage.

TABLE 2.—*Relation of ear characters of corn to yield, as shown by ear-to-row tests at the Kansas station, 1905 to 1909 and 1912.*

Ear character.[a]	No. ears tested.	Length of ear, inches.	Circumference, inches.	Yield, bushels per acre.
Length of ear:				
Long	566	9.3	....	48.2
Medium	508	8.7	....	48.4
Short	363	8.1	....	48.2
Number of rows per ear:				
16	178	....	....	43.5
18	271	....	....	41.4
20	131	....	....	39.9
Circumference of ear:				
Large	335	....	7.36	47.9
Medium	552	....	7.01	49.3
Small	344	....	6.60	49.6
Shelling percentage:				
82	98	....	....	50.8
84	168	....	....	49.8
86	126	....	....	49.9
88	88	....	....	49.6
Type of indentation:				
Very rough	327	....	....	49.2
Medium rough	576	....	....	52.6
Smooth and wrinkled	343	....	....	53.5
Character of tips:				
Well filled	308	....	....	51.7
Medium filled	478	....	....	51.8
Poorly filled	216	....	....	51.8
Character of butts:				
Well rounded	346	....	....	50.7
Partially rounded	423	....	....	51.0
Not rounded	168	....	....	51.0

[a] Yields are to be compared only within each group and not between the different groups.

INVESTIGATIONS AT THE MINNESOTA STATION.

Extensive data from both ear-to-row and mass-selection tests have been reported from the Minnesota station by Olson, Bull, and Hayes (16). Altho comparative results are given for several localities, those from the University Farm alone will be given here, since these are, in general, confirmed by the other tests.

In the ear-to-row tests, ear types of Minnesota No. 13 corn were compared for five to eight years; Minnesota No. 161 types were tested for three to six years. The ears planted each year have been divided equally into two groups, representing opposites as to any one character. The results for the two varieties are shown in Table 3.

Ears with small circumference yielded 0.2 percent more than the ears of large circumference. The extreme variation in circumference was from 5.5 to 7 inches. Long ears averaged 1.3 percent higher grain yield than short ears. The ears varied from 6.25 to 8.75 inches

TABLE 3.—*Relation of ear characters of corn to yield, as indicated by data from ear-to-row tests of Minnesota Nos. 13 and 161 corn at the Minnesota station.*

Ear character.[a]	Minnesota No. 13.			Minnesota No. 161.			Average, bu. per acre.
	Duration, years.	No. of ears tested.	Yield, bu. per acre.	Duration, years.	No. of ears tested.	Yield, bu. per acre.	
Circumference of ear:							
Small	6	226	57.8	4	178	62.5	60.1
Large	6		57.6	4		62.4	60.0
Difference							.1
Weight of ear:							
Light	6	230	57.5	4	212	62.3	59.9
Heavy	6		58.1	4		62.5	60.3
Difference							.4
Shelling percentage:							
Low percent	6	232	57.6	4	175	62.9	60.2
High percent	6		58.1	4		62.3	60.2
Difference							0
Filling of tips:							
Poor	8	315	57.4	6	251	62.3	59.8
Good	8		57.6	6		62.7	60.1
Difference							.3
Filling of butts:							
Poor	8	298	57.5	6	250	62.7	60.1
Good	8		57.4	6		62.3	59.8
Difference							.3
Uniformity of kernel:							
Nonuniform	8	310	57.2	6	249	62.6	59.9
Uniform	8		57.5	6		62.2	59.8
Difference							.1
Varietal type:							
Least true to type	8	321	57.2	3	126	61.0	59.1
Most true to type	8		57.7	3		61.5	59.6
Difference							.5
Length of ear:							
Short	6	233	57.7	4	174	62.0	59.8
Long	6		58.3	4		62.9	60.6
Difference							.8
Total scorecard score:							
Low scoring	8	309	57.2	3	126	60.1	58.6
High scoring	8		57.9	3		61.0	59.4
Difference							.8
Maturity:							
Less mature	5	191	56.3	3	122	60.6	58.4
More mature	5		56.3	3		61.0	58.6
Difference							.2
Maturity:							
Scoring below 84 percent	4	137	57.2	3	122	59.1	58.1
Scoring above 84 percent	4		59.0	3		61.1	60.0
Difference							1.9

[a] Yields are to be compared only within each group and not between the different groups.

extremes in weight being 0.4 and 0.7 pound. Ears of high and low shelling percentage yielded equally, the shelling percentage ranging from 78 to 90 percent.

The difference in yield between ears with well-filled tips and those with poorly developed tips was 0.5 percent in favor of the former. Ears with poor butts produced 0.5 percent more grain than those in length. Heavy ears yielded 0.7 percent more than light ears, the classified as having good butts. Ears with uniform kernels yielded 0.2 percent more than ears with nonuniform kernels.

Ears most true to variety type excelled in yield by 0.9 percent, and those scoring highest as judged by the Minnesota score card yielded 1.4 percent more than the ears scoring lowest.

When classified into equal groups according to maturity of ears, the most mature yielded 0.5 percent more than the least mature group. When the ears were grouped according to whether they scored above or below 84 percent maturity, the ears with highest maturity surpassed by 3.3 percent.

In no case was there more than about a half bushel difference in yield between the one-third ears scoring highest in any one character and the one-third ears giving the highest total score as judged by the score card before planting (Table 4). In the majority of cases the slight difference in yield is against the ears with the highest total score.

TABLE 4.—*Data from ear-to-row tests of two varieties of corn at the Minnesota station, showing comparison of the one-third ears having highest total score with the one-third ears scoring highest in each individual character.*

Character.	Minnesota No. 13.[a]		Minnesota No. 161.[b]	
	Actual yield.	Deviation from highest total score.	Actual yield.	Deviation from highest total score.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
Total score	58.3	....	61.3	....
Length	58.3	0	61.7	+0.4
Weight	58.4	+ .1	61.2	− .1
Circumference	57.9	− .4	62.0	+ .7
Shelling percent	58.2	− .1	61.5	+ .2
Butts	58.0	− .3	61.6	+ .3
Kernel uniformity	58.3	0	61.5	+ .2
Tips	58.3	0	61.9	+ .6
Variety character	58.7	+ .4	61.9	+ .6

[a] Eight-year averages.

[b] Six-year averages.

The coefficient of correlation was calculated for 9 different characters and yield, using 314 ear-to-row plats (Table 5). No significant correlation was found.

TABLE 5.—*Coefficients of correlation for various ear characters and yield, from ear-to-row tests conducted at the Minnesota Agricultural Experiment Station.*

Character.	Coefficient of correlation.
Length	+0.098 ±0.040
Weight	+0.047 ±0.044
Circumference	—0.052 ±0.041
Shelling percentage	+0.157 ±0.043
Butts	+0.006 ±0.037
Tips	+0.030 ±0.038
Kernel uniformity	+0.048 ±0.037
Variety character	+0.033 ±0.037
Total score	+0.119 ±0.038

Composite seed of 10 distinct ear types was planted in a comparative test during the years 1915 and 1916. As an average for the two years, ears of the show type were surpassed in yield by tapering ears, small ears, medium smooth ears, and ears with a low shelling percentage. The results are given in Table 6.

TABLE 6.—*Relation of ear type to yield in a bulk selection of Minnesota No. 13 corn grown at the Minnesota Agricultural Experiment Station, 1915 and 1916.*

Ear type.	Number of ears in test.	Yield, bushels per acre.	Deviation from show type, bu. per acre.
Show type	59	32.6	....
Long slender	71	31.8	−0.8
Short thick	92	31.9	−0.7
Tapering	72	34.6	+2.0
Cylindrical	39	30.2	−2.4
Small	80	33.1	+0.5
Rough	79	31.0	−1.6
Medium smooth	73	32.8	+0.2
High shelling percentage	34	32.1	−0.5
Low shelling precentage	34	34.4	+1.8

The Minnesota data, taken all in all, suggest that there is no dependable superiority of one ear type over another for seed purposes.

EXPERIMENTS IN ILLINOIS.

Sconce (17) reports 4-year tests on his farm with two varieties concerning kernel shape, germ size, and number of rows on the ear

(Table 7). The shape yielding lowest for one variety yields near the maximum for the other variety. Reid Yellow Dent ears having kernels with small germs yielded 3.8 bushels more grain per acre than ears with large germs. In the case of Johnson County White, the ears having large germs surpassed by 3.9 bushels. As an average for both varieties, yields from both germ types were practically equal.

TABLE 7.—*Relation of kernel size and shape to yield of corn, as shown by experiments of Sconce with Reid Yellow Dent and Johnson County White.*

Character.[a]	Yield in bushels per acre. Reid Yellow Dent. 1906.	1907.	1908.	1909.	1910.	Ave.	Johnson County White. 1907.	1908.	1909.	1910.	Ave.	Ave. both varieties.
Size of kernel:[b]												
17 x 12	....	88.8	64.2	68.2	98.4	79.9	....	....	....	....	....	....
18 x 12	....	87.1	66.5	63.0	96.1	78.2	80.5	71.4	80.8	63.3	74.0	....
19 x 10	....	....	....	....	....	....	85.0	72.0	68.2	82.0	76.8	....
19 x 11	....	81.7	64.5	71.0	94.3	77.9	....	....	....	....	....	....
20 x 10	....	77.0	64.5	58.4	92.1	73.0	....	....	....	....	....	....
20 x 11	....	....	....	....	....	....	84.0	60.0	82.4	89.3	78.9	....
21 x 11	....	....	....	....	....	....	81.2	69.0	66.9	80.0	74.3	....
21 x 12	....	....	....	....	....	....	84.0	64.0	62.0	89.6	74.9	....
Germ:												
Large	....	79.4	62.8	66.0	97.3	76.4	86.7	68.1	75.7	86.7	79.3	77.8
Small	....	84.2	64.5	74.3	97.7	80.2	80.0	66.0	70.0	85.6	75.4	77.8
No. of rows:												
16	46.6	80.2	61.5	....	95.1	70.8	79.7	62.8	....	81.0	74.4	72.6
18	48.1	82.9	66.0	....	92.1	72.3	85.1	68.7	....	88.1	80.6	76.4
20	48.8	80.8	61.5	....	98.1	72.3	86.0	72.7	....	87.3	82.0	77.1
22	43.5	77.8	65.0	....	95.4	70.4	81.2	60.0	....	79.0	73.4	71.9

[a] Yields are to be compared only within each group and not between the different groups.

[b] Length and width in thirty-seconds of an inch.

Averaging both varieties, ears with 16, 18, 20, and 22 rows of grain yielded, respectively, 72.6, 76.4, 77.1, and 71.9 bushels of grain per acre. These figures suggest that ears with a medium number of rows are superior under Illinois conditions. Funk (4) has a number of times called attention to the superiority, under Illinois conditions, of more slender ears with smoother and shallower kernels than the prevailing corn show standards called for.

EXPERIMENTS AT THE CORNELL (N. Y.) STATION.

Love and Wentz (12) report five years' results from ear-to-row tests, which indicate that ears of low shelling percentage (81.1 per-

cent) yielded 9 percent more grain per stalk than ears of high shelling percentage (87.6 percent). Coefficients of correlation have been calculated for grain yield per stalk and various ear characters during the two years 1909 and 1910 with Minnesota No. 13 and Funk Ninety Day (Table 8) and with the latter variety (Table 9) during the five years 1910 to 1914. No dependable correlation with yield was found for any of the ear characters.

TABLE 8. —*Coefficients of correlation of ear characters with grain yield per stalk, derived from data from ear-to-row tests at the Cornell University Agricultural Experiment Station.*

Seed-ear characters correlated with yield per stalk.	Minnesota No. 13.		Funk Ninety Day.	
	1909.	1910.	1909.	1910.
Length	−.099 ± .076	.241 ± .064	.300 ± .061	.058 ± .067
Weight	.094 ± .076	.015 ± .068	.323 ± .060	.090 ± .067
Number of rows	.260 ± .072	−.127 ± .067	−.061 ± .069	−.034 ± .067
Weight of kernels	....	.028 ± .068	....	.043 ± .067
Ratio of tip circumference to butt circumference	....	−.162 ± .066	....	.014 ± .067
Percentage of grain	....	−.177 ± .066	....	....

TABLE 9.—*Coefficients of correlation of ear characters with grain yield per stalk of a strain of Funk Ninety Day corn, derived from data from ear-to-row tests at the Cornell University Agricultural Experiment Station during the five years from 1910 to 1914.*

Seed-ear characters correlated with yield per stalk.	Coefficient of correlation.				
	1910.	1911.	1912.	1913.	1914.
Length	.013 ±.067	−.013 ±.067	−.102 ±.069	.026 ±.067	.165 ±.066
Average circumference	.187 ±.065	.249 ±.053	.360 ±.061	.104 ±.067	.134 ±.067
Ratio of tip to butt circumference	−.037 ±.067	−.087 ±.067	.019 ±.070	.085 ±.067	−.131 ±.067
Average circumference of cob	.169 ±.066	.126 ±.066	.274 ±.064	.130 ±.066	.185 ±.066
Weight	.023 ±.067	.108 ±.067	.249 ±.065	.156 ±.066	.099 ±.067
Percentage of grain	−.102 ±.067	−.173 ±.065	−.051 ±.069	−.046 ±.067	−.183 ±.066
Average weight of kernels	−.105 ±.067	−.114 ±.067	.112 ±.069	−.152 ±.066	.082 ±.068
Number of rows	.113 ±.067	.097 ±.067	.083 ±.069	−.067 ±.067	.032 ±.068
Average length of kernels	....	.038 ±.067	....	....	−.043 ±.068
Average width of kernels	....	.162 ±.066	....	....	.065 ±.068

INVESTIGATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE.

Biggar (1) reports the relative yields from long and short ears of five varieties tested in ear-to-row tests for several years. The long

ears consistently yielded from 1 to 9 percent more than the short ears (Table 10). The coefficients of correlation were calculated for yield and ear characters of the same five varieties (Table 11). A slight positive correlation is indicated for weight and length of ear, while a very slight negative correlation is suggested for number of rows and shelling percentage.

TABLE 10.—*Relation of length of seed ears and yield of corn, as shown by data from ear-to-row tests of the United States Department of Agriculture.*

Variety.	Period of test.	Length of ears.		Relative yields.	
		Short.	Long.	Short.	Long.
		Inches.	*Inches.*	*Percent.*	*Percent.*
Selection 77	1914–1917	7.9	9.0	100	101
Selection 120	1915–1917	8.3	9.3	100	101
Selection 119	1915–1917	8.3	9.5	100	109
Selection 133	1912–1914	6.7	7.5	100	107
Selection 204	1916–1918	7.5	8.5	100	103

TABLE 11.—*Coefficients of correlation between yield and ear characters of corn, from data from ear-to-row tests of the United States Department of Agriculture.*

Variety and year.	Weight.	Length.	Number of rows.	Shelling percentage.
Selection 77:				
1914	+.085 ± .073	+.177 ± .071	+.046 ± .073	−.309 ± .066
1915	+.261 ± .065	+.067 ± .071	−.028 ± .070	−.028 ± .070
1916	+.188 ± .061	+.120 ± .064	+.025 ± .063	−.105 ± .063
1917	+.064 ± .072	+.133 ± .072	−.146 ± .071	+.001 ± .073
Selection 120:				
1915	+.200 ± .090	+.175 ± .091	−.266 ± .089	−.148 ± .091
1916	+.076 ± .083	+.001 ± .083	+.062 ± .082	+.276 ± .077
1917	+.200 ± .091	+.279 ± .090	−.025 ± .095	−.117 ± .093
Selection 119:				
1915	+.296 ± .074	+.231 ± .079	+.063 ± .081	+.067 ± .082
1916	+.131 ± .083	+.354 ± .075	−.147 ± .082	−.063 ± .084
1917	+.565 ± .061	+.330 ± .081	−.131 ± .088	+.155 ± .088
Selection 133:				
1912	+.070 ± .079	+.063 ± .080	−.077 ± .079	−.370 ± .076
1913	+.334 ± .072	+.381 ± .071	+.061 ± .081	−.017 ± .081
1914	+.130 ± .070	+.301 ± .066	+.015 ± .071	+.166 ± .069
Selection 204:				
1916	+.145 ± .093	+.082 ± .096	−.024 ± .095	−.368 ± .082
1917	−.074 ± .062	+.068 ± .064	−.040 ± .063	+.042 ± .063
1918	+.097 ± .075	+.276 ± .071	+.055 ± .075	−.263 ± .070

TESTS AT THE VIRGINIA STATION.

Hutcheson and Wolfe (7) offer two years' data from ear-to-row tests in support of the customary score card as a guide for selecting

high yielding seed ears. In all, 140 ear-to-row tests were made in 1916 and 98 tests in 1917. The yields from the 12 highest yielding rows in 1916 and the 9 highest yielding rows in 1917 are contrasted with the yields from the 10 lowest yielding rows of 1916 and the 11 lowest yielding rows of 1917 (Table 12). The ears harvested from these highest and lowest yielding rows were then scored according to the Virginia score card. As an average for the two years, the lowest yielding group fell 17.7 bushels per acre short of the highest group, which in turn conformed most nearly to the score-card requirements in nearly all particulars. The ear-to-row plats in this experiment consisted of two rows 66 feet long, which provide for a total of about 36 hills from each ear.

TABLE 12.—*Relation between yield and various seed ear characters of the crop harvested from the high and from the low yielding rows, in an ear-to-row test with Boone County White corn at the Virginia Agricultural Experiment Station, in 1916 and 1917.*

Character.	Measurement of score.		
	High yielding strains.	Low yielding strains.	Difference.
Yield per acre (bushels)	72.5	54.8	−17.7
Average length (inches)	8.5	8.0	− .5
Average circumference (inches)	6.8	6.6	− .2
Ratio of tip to butt circumference	.9	.9	0
Average circumference of cob (inches)	4.2	4.0	− .2
Percentage of grain	82.4	82.3	− .1
Average number rows	16.6	16.5	− .1
Average length of kernels (inches)	.4	.4	0
Uniformity of exhibits (percent)	52.2	48.1	− 4.1
Shape of ear and trueness of type (percent)	48.5	44.6	− 3.9
Character of tips (percent)	43.5	36.3	− 7.2
Character of butts (percent)	49.3	48.0	− 1.3
Uniformity of kernels (percent)	49.9	45.8	− 4.1
Shape of kernels and size of germ (percent)	52.6	47.0	− 5.6
Space between kernels (percent)	62.3	61.9	− .4
Space between rows (percent)	57.6	58.9	+ 1.3

In addition to the authors, Carrier (2) has interpreted these data as confirming the practical value of the score card in seed-corn selection.

There may be some doubt, however, as to whether the score-card differences indicated in Table 12 should be assigned as the underlying cause of this wide difference in yield. The superior score of the ears harvested from these high-yielding plats may, perhaps, be no more the cause than the effect of high yield. The causes may be entirely

foreign to ear-type considerations. Variations of as much as 5 percent in the perfection and uniformity of ear and kernel development and 25 percent in yield per acre may easily result from soil heterogeneity and stand variations within a series of 200 or 300 short corn rows. Any adverse environmental factor is likely systematically to reduce both the yield and score of an ear-to-row plat. The manner of comparison reported in this test does not appear to provide for the random and accidental distribution of inherently high and low scoring types in the field. The method employed permits the combination of any yield factors, and the most adverse combinations, whether seed or environmental, determine the opposing groups of plats. The more adverse combinations commonly result in the lowest scoring ears harvested.

In a test of this character it would appear that the aim sought could be best achieved by correlating the yield with the score of the corn planted, rather than the score of its progeny, and then comparing the yields from the high and low scoring types.

TESTS AT THE NEBRASKA STATION.

The early investigations at the Nebraska station regarding the relation between ear characters and yield were begun by Lyon in 1904 and continued till 1911 by Montgomery. A lot of rather long, slender, smooth ears with grains of only medium depth was selected from a general lot of Reid Yellow Dent corn harvested in 1904. The ears were grown in 1905 in comparison with the original standard Reid. During the three succeeding years this test was continued, selecting each year the long smooth ears grown from the long smooth ears of the previous year (14). As an average for the four years' test (Table 13), the long smooth type surpassed the standard type, with its greater circumference and rougher and deeper kernels, by 7.8 percent in yield.

TABLE 13.—*Average yield in bushels per acre obtained from long smooth ears of Reid Yellow Dent corn compared with the standard medium rough type of that variety at the Nebraska Agricultural Experiment Station during the four years from 1905 to 1908.*

Year.	Yield, bushels per acre. Smooth type.	Standard type.
1905	69.7	59.4
1906	47.2	51.4
1907	69.9	64.1
1908	56.8	51.2
Average	60.9	56.5

In 1909 five prize-winning show exhibits from Illinois, Indiana, and Ohio were compared for yield with ordinary corn of five varieties, obtained in Nebraska at a distance of fifty or more miles from the experiment station, and also with seven varieties secured locally. The show character of the seed from other States in no way offset the more important consideration of local adaptation (15). The average yields of these three lots of corn were, respectively, 39.8, 45.6, and 48.8 bushels per acre.

In 1910 five yellow and five white exhibits of good show type and five exhibits of poor show type were obtained from the Nebraska State Corn Show. When these three lots were compared for yield at the experiment station, they produced, respectively, 56.1, 55.8, and 56.9 bushels per acre.

In 1910 a number of Nebraska corn growers responded to a request to send to the experiment station samples of corn which they regarded as consisting of "good and selected" ears and other samples of "poor and run-down" ears. These were tested at the station and averaged 53.6 and 53.2 bushels, respectively.

During the three years from 1911 to 1913 a "high-yielding ear" contest was conducted in cooperation with the Nebraska Corn Improvers' Association. A large number of farmers each year entered an ear of corn which they regarded as a high-yielding ear. These were tested the following year by the experiment station, in an ear-to-row test, and the results were shown at the following corn show The ears represented a great variety of types. It became evident from these tests that there was no dependable relation between type of ear and yield produced. For example, in 1911 an experienced corn-show exhibitor won first premium at the State show on a single ear which was judged by the score card, while a similar ear which he entered in the high-yielding ear contest yielded the least of any of the 28 ears tested that year.

In 1917 the grand champion single ear and the grand champion ten ears of the State Corn Show were grown and entered by the same exhibitor, Glen Wilson, who is a young farmer residing about 50 miles northeast of the experiment station. In the season of 1917 both exhibits were tested at the experiment station in comparison with the growers' bulk seed from which the exhibits had been very carefully selected, and also in comparison with Hogue Yellow Dent corn which has never undergone any selection for a fixed type and consists of a great mixture of types. Wilson's grand champion single ear yielded at the rate of 45.6 bushels per acre, his State champion 10-ear

exhibit yielded 49.5 bushels, and his bulk farm seed yielded 50.8 bushels. In comparison, the Hogue Yellow Dent yielded 51.2 bushels. These results indicate that no yield improvement had been effected by selecting the high scoring types.

The butts, middles, and tips of Nebraska White Prize corn were compared (Table 14) during the four years 1914 to 1917 and yielded, respectively, 60.1, 60.7, and 61.7 bushels per acre. This suggests that all parts of an ear of corn have inherently about equal yielding power. In connection with this experiment, attention may be called to the statement by Miss Mary Lacy (10) summarizing all experiments to date (1915) on this subject: "In four out of eighty-one cases reported, we may be sure that the yield has been increased by the use of tip seed, and in the other cases there is no evidence that the use of tip seed has decreased the yield."

TABLE 14.—*Annual and average yields in bushels per acre obtained from butts, middles, and tips of Nebraska White Prize corn at the Nebraska Agricultural Experiment Station, 1914 to 1917.*

Seed planted.	Yield, bushels per acre.				
	1914.	1915.	1916.	1917.	Average.
Butts	48.8	77.0	65.0	49.6	60.1
Middles	48.0	76.8	68.8	49.4	60.7
Tips	49.6	75.3	69.3	52.7	61.7

During the four years 1914 to 1917 four distinct ear types were selected from the general variety of Nebraska White Prize corn and tested for yield (Table 15). Continuous type selection was not practiced in this test. The types were (1) large rough, (2) short rough, (3) short smooth, and (4) long, slender smooth. They yielded, respectively, 51.4, 57.1, 56.7, and 58.8 bushels per acre as a 4-year average. The original unselected corn yielded 58.1 bushels in comparison. The long, slender, smooth type of ear was the highest yielder and produced 14.4 percent more than the large rough type, but only 1.2 percent more than the original unselected corn. In this test the rough ear type planted had distinctly deeper kernels, larger ear circumference, and one-fourth more rows per ear. The characters tended to come true to type in the progeny, tho in a very marked lesser degree, as shown in Table 16, due to their complex germinal constitution resulting from promiscuous pollination.

TABLE 15.—*Annual and average yields in bushels per acre from different ear types of Nebraska White Prize corn at the Nebraska Agricultural Experiment Station, 1914 to 1917.*

Type of ear.	Yield, bushels per acre.				
	1914.	1915.	1916.	1917.	Average.
Original	[illegible]	[illegible]	[illegible]	[illegible]	58.1
Large rough	30.0	65.3	64.4	45.9	51.4
Short rough	44.4	68.9	65.1	49.9	57.1
Short smooth	45.0	72.6	60.1	49.2	56.7
Long slim smooth	48.7	66.4	65.2	54.9	58.8
Number of duplications	6	8	14	7	

TABLE 16.—*Relation of ear type to yield of a bulk selection of Nebraska White Prize corn grown at the Nebraska Agricultural Experiment Station. Four-year average, 1914 to 1917.*

Ear type.	Ear length.	Ear circumference.	Number of rows per ear.	Ear weight.	Length of 100 kernels.	Width of 100 kernels.	Yield per acre.
	Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	*Bu.*
MEASUREMENTS OF EARS PLANTED.							
Long, large, rough	10.4	7.8	22	1.1	59	31	51.4
Short, large, rough	7.3	7.5	20	0.8	58	32	57.1
Short, slim, smooth	7.7	5.7	16	0.5	45	32	56.7
Long, slim, smooth	10.4	6.2	16	0.8	46	32	58.8
MEASUREMENT OF EARS HARVESTED.							
Long, large, rough	6.3	5.9	18.2	.36	49	33	51.4
Short, large, rough	6.3	5.9	17.8	.41	50	32	57.1
Short, slim, smooth	6.4	5.5	16.7	.37	47	32	56.7
Long, slim, smooth	6.8	5.6	17.4	.41	47	31	58.8

In 1916 and 1917 deep-grained rough ears and shallow-grained smooth ears of Hogue Yellow Dent corn (Table 17) were compared with unselected bulk seed of the same variety. The 2-year average yields were, respectively, 64.0, 69.6, and 64.5 bushels per acre.

TABLE 17.—*Relation of ear type to yield in Hogue Yellow Dent corn as shown by acre yields in bushels at the Nebraska Agricultural Experiment Station, 1916 and 1917.*

Ear type.	Yield, bushels per acre.		
	1916.	1917.	Average.
Deep rough kernels	72.0	56.0	64.0
Shallow, smooth kernels	80.1	59.2	69.6
Unselected	71.7	57.4	64.5

Further evidence of the undesirable nature of deep grained corn was secured indirectly in 1917. The ears harvested on December 29 from a field of Hogue Yellow Dent corn at the experiment station were divided into groups according to their apparent soundness, maturity, and solidity. These groups were tested for germination and the average length of kernel was determined for each (Table 18). Beginning with the most mature group, the germination for the five groups were, respectively, 93, 59, 14, 5, and 0 percent, and the corresponding kernel lengths were 0.49, 0.50, 0.52, 0.54, and 0.57 inch. On December 29 these groups contained, respectively, 15, 16, 19, 21, and 28 percent moisture. Corresponding groups at the time of the first killing frost, on October 8, 1917, contained 35, 39, 43, 47, and 50 percent moisture. The high moisture content is due to this having been an abnormal season for corn.

TABLE 18.—*Relation of kernel length to moisture content and freezing injury of corn when husked from the field during the fall and winter of 1917.*

Condition of corn at time of first frost, October 8.	Moisture in grain gathered on—		Germination of corn gathered on—		Length of kernel,
	Oct. 8.	Dec. 29.	Oct. 8.	Dec. 29.	Dec. 29.
	Percent.	*Percent.*	*Percent.*	*Percent.*	*Inches.*
Fairly well matured and ears solid	35	15	98	93	0.49
Somewhat rubbery and ears twist	39	16	94	59	.50
Very rubbery and grain medium soft	43	19	92	14	.52
Grain very soft	47	21	92	5	.54
Late dough stage	50	28	82	0	.57

The Nebraska type studies indicate superior yields for shallower and smoother type selections than is customary in the more favored corn sections of the State. The sorts worked with were all standard full season varieties. I am not inclined to believe that this increased yield is due merely to the difference in ear type, but rather because it represents slightly earlier maturing and less rank growing plants.

Whether a corn grower may effect the greater improvement in the yield of his corn by selecting the smoother or rougher type of ear will probably depend upon whether his corn is now somewhat too small and early, or whether it is too late maturing and rank growing. In farm practice this adjustment of plant type to local conditions may be gradually effected by either selecting seed from the plants in the

field which possess the desired characteristics or else by selecting for seed those ears which suggest greater or less earliness and vegetative growth. In well-adapted corn it will probably prove advantageous to select for seed a mixture of ear types. Fancy ear considerations, such as perfect tips and butts, cylindrical ears, and uniformity of ears in size and shape, uniformity of kernels in size, shape, and indentation, and straightness of rows, are nonessential trom the yield standpoint.

In general, for most Nebraska conditions at least, and probably for all regions not more favorably situated, distinctly deep-grained and rough ear types should be avoided. A distinct change in sentiment has in recent years taken place among some of our most prominent corn men in Nebraska, and they assert that experience has taught them to get away from the old-time rough, deep-grained corn and to follow a middle of the road policy.

EAR TYPE AND DISEASE.

It would appear that investigations of the root, stalk, and ear rot diseases of corn have not progressed sufficiently far to warrant conclusions regarding their significance in connection with ear-type performance. Disease may be one cause of rough, starchy, and chaffy kernels. But rough, starchy kernels are certainly not necessarily a criterion of disease. We probably can concede that the deep, rough, starchy kernel is at least as well adapted to the highly favored corn district of Franklin County, Ind., which is noted for its superb corn of this type, as some other type might be. Ears bearing evidence of disease or low viability should not be chosen for seed. The recent work of Hoffer and Holbert (5, 6) and others will doubtless stimulate more general investigations along these lines.

EXTREME UNIFORMITY OBJECTIONABLE.

In general, the principle of selecting for extreme uniformity in ear type or other plant characteristics is faulty. Corn is normally a complex and cross-fertilized crop. Artificial inbreeding of corn in which an ear is fertilized by pollen from the same plant greatly reduces the yield of the succeeding corn grown from the inbred seed. After four or five years of such inbreeding not more than one-fourth the normal production may be expected. The plants and ears, however, all come to be uniform in type. No one ever attains with his corn such a degree of purification of the germ elements by practicing rigid type selection, but there is a tendency to approach in a small

measure such purification and reduced production. The principle of broad breeding in which varied types enter into the constitution of the corn is correct.

A striking and unexpected occurrence of such reduced production by unconsciously restricting the seed to too great a degree of purity may be cited as follows: The Nebraska experiment station began ear to-row corn-breeding experiments in 1902. It was pioneer work and no one knew what was the best procedure to follow, so several plans were carried out and have been continued to the present. Of the 100 ears planted and tested individually for yield by the ear-to-row method, ear No. 64 surpassed all others. In order to avoid crossing with other and perhaps lower yielding ears, the remnant of ear No. 64 was planted off by itself the following year in an isolation plat. This procedure with strain No. 64 has been continued each year, with the result that, as an average for the seven years (1911–1917) when grown in a yield test with the original Hogue Yellow Dent corn, from which it was once selected as the premier, it has yielded 47.7 bushels as compared with 53.6 bushels per acre. This is practically a 6-bushel inferiority. In a comparable test in which four high-yielding ear-to-row strains were originally mixed together, and continued each year in an isolation plat, the yield has been nearly 1.4 bushels more than the original corn and 7.3 bushels superior to strain No. 64.

The Nebraska results from continued selection for high *vs.* low ratio of leaf area in proportion to dry matter may serve as a further illustration of unexpected reduction in yield due to continued type selection. During the seven years from 1911 to 1917 these two strains were compared with their F_1 hybrid as well as the original Hogue Yellow Dent from which they were selected. The strains originated from individual plants which differed in their amount of leaf area in proportion to dry matter. These characters had become fairly well fixed by continued selection for three years. They were thereafter grown in isolation plats, selecting each year well-developed ears from plants of the desired type. The low leaf area strain averaged 1,034 square inches per stalk and the high leaf area measured 1,340 square inches, while the original corn averaged 1,195 square inches of leaf area. Under comparable conditions during the seven years the yields of the low leaf area, high leaf area, original, and F_1 hybrid Hogue Yellow Dent have been, respectively, 51.9, 47.8, 53.4, and 53.5 bushels per acre.

As Olson, Bull, and Hayes (16) have also pointed out for the classical type selection by Hopkins and Smith in Illinois, for high and low oil and high and low protein, we may have an excellent example of reduced yield resulting from continued type selection.

Various degrees of closeness in breeding may be artificially effected. Results at the Nebraska Agricultural Experiment Station indicate that the closer the breeding, the smaller the yield. Thus, as a 7-year average, Hogue Yellow Dent corn which was

1. Inbred, yielded 16.8 bushels.
2. Narrow bred within a strain, 42.2 bushels (seed continued by single ear, fertilized by composite pollen from sister plants).
3. Broad breeding within a strain, 49.2 bushels (seed continued from composite ears, fertilized by composite pollen from sister plants).
4. Cross breeding between strains, 54.0 bushels.
5. In comparison with the above, the original wind-fertilized Hogue Yellow Dent corn has yielded 53.1 bushels per acre.

SUMMARY.

A review of the available data indicates that, within reasonable limits at least, variations in ear characters are rather neutral in their effect upon the yield of dent corn, except when they are definitely linked with special adaptive growth characteristics of the plant. Thus, slender ears with smooth, shallow kernels tend to be produced on earlier maturing, smaller, and less rank growing plants than are large, rough, deep-kerneled ears of the same variety. In the States of Kansas, Nebraska, Ohio, and Illinois, where the tendency has been to grow too large and late maturing corn types, selection of the rather long, slender, medium smooth ears, with kernels of medium depth and medium shelling percentage, results in somewhat increased production. Ear and kernel characters, aside from those known to indicate soundness and special adaptation, have little significance as indicators of high producing seed ears.

There are indications that close type selection, if long continued, may even reduce productivity, thru an approach toward gametic purity for the selected characters. This may also account in part for increased yields sometimes obtained from F_1 variety hybrids. Many institutions and individuals have practiced continued type selection in order to achieve uniformity and have perhaps unwittingly introduced an element of close breeding.

It has recently been proposed that the root, stalk, and ear rot diseases are somewhat associated with dull and starchy kernels and with

discolored or shredded shank attachment. Further and more general investigations may disclose the full significance of ear characteristics as disease indicators. The proposed control of these corn diseases opens a new and important field for investigation.

LITERATURE CITED.

1. Bigger, H. H. The relation of certain ear characters to yield in corn. *In* Jour. Amer. Soc. Agron., 11: 106–113. 1919.
2. Carrier, Lyman. A reason for the [illegible] rn experiments. *In* Jour. Amer. Soc. [illegible]
3. Cunningham, C. C. The relation of ear characters of corn to yield. *In* Jour. Amer. Soc. Agron., 8: 188–196. 1913.
4. Funk, Eugene. Ten years of corn breeding. *In* Amer. Breeders Mag., 3: 295–302. 1912.
5. Hoffer, G. N., and Holbert, J. R. Selection of disease-free seed corn. Ind. Agr. Expt. Sta. Bul. 224. 1918.
6. Holbert, J. R., and Hoffer, G. N. Control of root, stalk, and ear rot of corn. U. S. Dept. Agr. Farmers Bul. 1176. 1920.
7. Hutcheson, T. B., and Wolfe, T. K. Relation between yield and ear characters in corn. *In* Jour. Amer. Soc. Agron., 10: 250–255. 1918.
8. Kiesselbach, T. A., and Keim, F. D. The regional adaptation of corn in Nebraska. Nebr. Agr. Expt. Sta. Research Bul. 19. 1921.
9. Kiesselbach, T. A., and Ratcliff, J. A. Freezing injury of seed corn. Nebr. Agr. Expt. Sta. Bul. Research Bul. 13. 1920.
10. Lacy, Mary G. Seed values of maize kernels; butts, middles, and tips. *In* Jour. Amer. Soc. Agron., 7: 159–171. 1915.
11. Love, H. H. The relation of certain ear characters to yield in corn. *In* Proc. Amer. Breeders' Assoc., 7: 29–40. 1912.
12. ——, and Wentz, J. B. Correlations between ear characters and yield in corn. *In* Jour. Amer. Soc. Agron., 9: 315–322. 1917.
13. McCall, A. G., and Wheeler, C. S. Ear characters not correlated with yield in corn. *In* Jour. Amer. Soc. Agron., 5: 117–118. 1913.
14. Montgomery, E. G. Experiments with corn. Nebr. Agr. Expt. Sta. Bul. 112, p. 19–24. 1909.
15. ——. Native seed corn. Nebr. Agr. Expt. Sta. Bul. 126. 1912.
16. Olson, P. J., Bull, C. P. and Hayes, H. K. Ear type selection and yield in corn. Minn. Agr. Expt. Sta. Bul. 174. 1918.
17. Sconce, H. J. Scientific corn breeding. *In* Proc. Amer. Breeders' Assoc., 7: 43–50. 1911.
18. Williams, C. G., and Welton, F. A. Corn experiments. Ohio Agr. Expt. Sta. Bul. 282, p. 84–91. 1915.

VIABLE LEGUME BACTERIA IN SUN-DRIED SOIL.[1]

Wm. A. Albrecht.[2]

Instructions for the general practice of inoculating soils with *Pseudomonas radicicola* for new legumes by transfer of infected soil usually include the precaution that the infected soil must not be exposed to the sunlight (1), (2), (3), (4), (8).[3] It is generally believed that the organism is killed by such treatment or injured to such an extent that the soil will not serve effectively as inoculant for the legume crop on the new soil. It is sometimes recommended that the soil used for inoculation shall be scattered only on rainy or dark days, or that if used on a bright sunny day it shall be scattered in advance of some tillage operation (2) and worked into the soil immediately, since "the desirable bacteria are readily killed by exposure to the sun" (1). Such statements would lead to the belief that the organism is readily killed, and that the infected soil becomes worthless as inoculating culture by allowing it to dry in the sun.

The apprehension of this danger seems to have arisen from fancy rather than fact. It may have come from the general knowledge that sunlight is a good sterilizer, but evidently not from definite experimental work. To find out whether sunlight actually destroys the efficiency of infected soil as an inoculating agent, we have made some tests on soils used in a study of the longevity of *Pseudomonas radicicola.*

Four fertile silt loam soils, of two different soil types, each of which produced good crops of thoroughly inoculated red clover and soybeans one year, were collected in the following spring and divided into equal parts. One-half of each sample was spread out as a thin layer about ¼ inch deep in direct sunlight until thoroly dry, and then exposed for two months in a similar way on a bench in a greenhouse. The other half was taken into a dark room for drying. Both soils were later stored away from the light and heat, in sterilized jars, with every precaution against contamination, and then tested for their

[1] Contribution from Missouri Agricultural Experiment Station, Columbia, Mo. Received for publication May 23, 1921.

[2] Associate Professor of Soils.

[3] Reference by number is to "Literature cited", p. 51.

ability to produce nodules on these two crops, as compared with the original soil left in the field.

To determine whether the *Pseudomonas radicicola* remained viable, soybean and red clover plants were grown in these soils within sterile bottles carefully handled to prevent the introduction of this organism from any other source. The production of nodules on plants grown from sterile seeds under such conditions would necessarily mean that the organism was living in the soil and had retained its power of infection. Approximately 750 grams of soil were put into wide-necked bottles of about 2-liter capacity, with inverted pint cups as covers; moistened with sterile water and planted with sterilized red clover and soybean seeds (7). From 2 to 4 plants of soybeans and 3 to 6 clover plants were grown in each bottle. After sixty days[4] the plants, tho small, were carefully removed by washing out the soil with running water and examined for nodules. As a check on the method plants were grown in sterile sand. These remained free from contamination.

The above test was repeated at intervals of six months for five times with the results given in the table:

Nodule Production in Soils with Different Treatments.

Soil Treatment.	Nodules per plant. Soybean.	Red Clover.
Dried in the sun and stored	5[5] (0–15)	8 (4–14)
Dried in the dark and stored	5 (0–14)	9 (2–22)
No treatment. Fresh field soil	9 (2–20)	10 (5–19)

From the above table it is evident that in the trials with the soybean organism there was a slight increase in the number of nodules produced with the decrease in the severity of the treatment, while for the red clover organisms there was less difference. The red clover thrives better under such adverse conditions as those existing in a closed container and bears many small nodules, but in case of both these legumes the growth was excellent and the plants were thrifty. The soil dried in the sun and that dried in the dark produced nodules on both kinds of legumes as well as the untreated fresh soil, hence the bacteria must have lived thru the treatment.

[4] In speaking of red clover Hunt (5) says, "Under greenhouse condition tubercules appear upon the main root in two weeks and upon the branches in four weeks." On basis of this statement sixty days were taken as time for plant growth to produce nodules.

[5] Figures are the averages from twenty bottles representing approximately a total of 64 soybean and 100 clover plants. Figures in parenthesis denote the range of numbers of nodules per plant.

In this method of testing soil for the presence of the legume organism—and at present it is the only method available—such numbers of readily visible nodules on plants so small indicate that the *Pseudomonas radicicola* was effective for inoculating the following seeding whether the soil containing it was dried in the absence or in the presence of direct sunlight, and that the dried soil stored for 30 months was as good for inoculating purposes as the fresh moist soil gathered from the field. These results indicate that direct sunlight and desiccation are not as destructive to this organism in its native habitat as has been stated (6), and that even tho some of the legume bacteria may be killed when the infected soil is exposed to the sun, the number of them so destroyed is not great enough to impair seriously the efficiency of such soil as an inoculating culture.

Literature Cited.

1. Brown, P. E. Soil inoculation Ia. Agr. Exp. Sta. Cir. 43, 3. 1918.
2. Coe, H. S. Sweet clover, growing the crop. U. S. Dept. Agr. Farm. Bull. 797, 28. 1917.
3. Hopkins, C. G. Nitrogen bacteria and legumes. Ill. Agr. Exp. Sta. Bull. 94, 327. 1912.
4. Hopkins, C. G. Soil fertility and permanent agriculture, Ginn & Co., Boston, 1910.
5. Hunt, T. F. Forage and fiber crops in America. Orange Judd Co., New York, 1911.
6. Marshall, C. E. Microbiology, 2nd edition. Blakiston's Son & Co., Phila., 1917.
7. Prucha, M. J. Physiological studies of bacillus radicicola of Canada field pea. Cornell Agr. Exp. Sta. Memoir 5, 10. 1915.
8. Williams, C. G. Alfalfa culture. Ohio Agr. Exp. Sta. Mo. Bull., 175. June, 1917.

AN APPLICATION OF CLOSE BREEDING IN CORN WHICH PRODUCED NUMEROUS ALBINOS.[1]

A. N. Hume.[2]

In South Dakota Bulletin 186 it was attempted to set down some definite procedure for laying out a corn-breeding plot that should conform as nearly as possible to known principles, and also be practicable in farm management. It is admittedly a task to know all principles

[1] Contribution from the South Dakota Agricultural Experiment Station, Brookings, So. Dak., for publication September 12, 1921.

[2] Agronomist and superintendent of substations.

involved, and it is a puzzle to observe those principles in offering a practical plan to corn growers whereby they can depend on securing strains of corn bearing, for example, "determiners" of high yield.

The writer is attempting to develop "All Dakota" corn by applying a system of (1) continuous selection, (2) hybridization, (3) introduction of promising new strains. The present season is the sixth year for the breeding plot under discussion, and up to the present "All Dakota" appears to have developed favorably to the system.

It is of importance to develop a "variety" of corn for any given state. It is more important to define the steps that are essential practically from the standpoint of actual corn growers. For instance, is continuous selection essential in practical corn breeding? If so, in what respect?

The occurrence of albinos in certain rows of our "All Dakota" breeding plot this season may have some bearing upon this and similar questions. These albinos appeared within certain rows, which were collectively intended for the introduction of ears representing strains from outside sources. All of the albinos, however, appeared in the "sire" rows, which had been planted with kernels from either one of two ears, numbered, respectively, 19– and 21–. These two ears (more accurately the kernels borne by them) carry identical hereditary factors so far as our record can show. Moreover, both are close-bred ears (kernels) from the same "sire" row of "All Dakota" breeding plot of 1920. The pedigree of both ears is indicated by the following arrangement of ear numbers:

- 19– and 21–
  - 414
    - 392
      - 248
        - 112
        - 174 (S.D. 86)
      - 296
        - 140
        - 188
    - 302
      - 298
        - 140
        - 198 (S.D. 86)
      - 202
        - 188
        - 104
  - 414
    - 392
      - 248
        - 112
        - 174 (S.D. 86)
      - 296
        - 140
        - 188
    - 302
      - 298
        - 140
        - 198 (S.D. 86)
      - 202
        - 188
        - 104

Both produced numerous albinos this year (1921), and there happened to be no other albinos in the plot.

Albinism is apparently forced to show itself as a result of close breeding or inbreeding. Would it not follow that the surviving selected progeny of inbred or close-bred ears (kernels) would be comparatively freer from the "genes" of albinism; and in like manner freer from other fatal or undesirable "genes"? Accordingly, would not the close-bred seed corn from "sire rows" be especially valuable in a succeeding year, for the reason that it is strongly "homozygote," and thus able to produce hybrid seed when crossed in a following generation?

Some of the considerations just set down may reinforce the idea that the usual prejudice against inbreeding and close breeding in *corn and gregarious animals* is founded on the apparent ill effect of such breeding upon immediate progeny, even tho such breeding in the long run may be beneficial to the race, by forcing undesirable "genes" to be eliminated.

BOOK REVIEW.

Breeding Crop Plants. *By H. K. Hayes and R. J. Garber. McGraw-Hill Book Co., New York, 1921, pp. 328.*—This book is one of the "Agricultural and Biological Publications" edited by Charles V. Piper. It will be of unusual interest and great value to agronomists, plant breeders, plant pathologists, and all students of economic botany, especially those directly interested in crop improvement. There have been available several text and reference books on genetics and plant breeding published in English, but heretofore Früwirth's "Die Zuchtung der Landwirtschaftlichen Kulturpflanzen" has been the only available reference work on the breeding of crop plants.

The style in which the book is written is clear and pleasing, and because of the well-chosen and logically arranged subject matter the book will undoubtedly prove a most welcome and useful text for courses in crop breeding or crop improvement. Particularly is this true since the work here reviewed is the first American or English book on the subject. A few typographical and other minor errors have crept in, but for the most part the physical make-up and presentation of the subject matter of the book are excellent.

The purpose of the book, as stated by the authors, is to outline methods of breeding in relation to the underlying principles involved and to present what are coming to be recognized as proper field methods of carrying on these studies, as well as to summarize the known facts regarding the mode of inheritance of many of the important characters of crop plants.

The book contains 66 text figures, 75 tables, a glossary, and a rather extensive bibliography. The subject matter is divided into 19 chapters.

In the Introduction attention is directed to the work of the early plant breeders, to the relation of certain biological principles to plant breeding, and to the value of crop improvement in relation to a more efficient agriculture. The chapter on Plant Genetics reviews genetic principles in some detail, tho the authors state that a previous knowledge of the principles of genetics is a necessity if the student of crop breeding is to pursue his work in the most logical manner. In the next chapter the important crop plants are grouped according to their pollination habits, and an explanation of hybrid vigor is given. Under the heading, Field Plot Technic, the authors discuss the use of checks and replicated plots, the value of probable error in the interpretation of experimental results, and the effect of competition. The size and shape of plots, border effect, and climatic variations are also considered.

The chapter on Inheritance in Wheat includes an account of the behavior in heredity of the characters of the plant such as disease resistance, winter hardiness, stiffness of straw, and earliness. The inheritance of spike characters such as compactness, chaff color, presence or absence of beards, and seed characters, including color and texture, are given detailed consideration.

In succeeding chapters similar but somewhat less extensive discussions are presented of inheritance in oats, barley, rye, buckwheat, and rice.

In discussing Methods of Breeding Small Grains, the authors describe the system of record-keeping in use at the Minnesota Agricultural Experiment Station. The use of the methods of selection and of crossing in small grain breeding is also discussed. A brief account of the technic of harvesting and thrashing is added.

In the chapter on Selection with Self-fertilized Crops an historical account of the early work in pure line or pedigree selection is given, followed by examples of some of the more recent economic results of selection in wheat, oats, and other crops. Some of the results of crossing as a means of improving self-fertilized crops are presented.

The chapter on Maize Breeding describes the origin and species of maize. This is followed by a detailed account of the inheritance of characters, including endosperm characters and a discussion of xenia, plant characters, seed and ear characters, size characters, and chemical composition. In the section on corn improvement the following subjects are discussed in the light of recent experimental work: Relation of ear characters to yield; ear-to-row breeding; relation between heterozygosis and vigor; immediate effect of crossing on size of seeds; F_1 varietal crosses; and isolation of homozygous strains.

The chapter on Grasses, Clovers, and Alfalfa is rather brief, particularly that part of it dealing with alfalfa.

The material on Potato Improvement includes an account of the origin of the potato and description of the species, the inheritance of characters, the production of new forms, difficulties of obtaining crossed seed, improvement thru seedling production, and clonal selection.

Information on the Breeding of Vegetables is presented in a chapter which includes the results of breeding experiments with the following close-fertilized crops: peas, beans, tomatoes, and peppers. The vegetables which are cross-fertilized include the radish, beet, asparagus, and members of the mustard and cucurbit families. Less than a page is devoted to the material on the breeding of beets, including the sugar beet. The very interesting historical material on sugar-beet improvement in Europe is only briefly mentioned, and nothing is said of the rather extensive biometrical studies of Pritchard and Harris in this country.

The chapter on Fruit Breeding is complete enough to meet the needs of the general student of crop improvement, but is not intended to satisfy the requirements of those especially interested in the breeding of horticultural plants.

The concluding chapter deals with the Farmers' Methods of Producing Pure Seeds. The importance of the determination of better varieties adapted to the locality where grown is emphasized. Good seed, methods of seed production and distribution, seed certification, and practical methods of corn improvement are described.—J. H. P.

AGRONOMIC AFFAIRS.

CHANGE OF THE EDITORSHIP OF THE JOURNAL.

With the completion of Volume 13, C. W. Warburton retires from the editorship after a period of seven years of unselfish and untiring service in this capacity, during the first four of which he also served as the Secretary of the Society. During his editorship the JOURNAL has steadily grown in both the quality and the quantity of published material, until finally the restrictions imposed by the financial resources of the Society became the only limiting factor in the volume of material which could be published.

Mr. Warburton has turned over to the present editor nearly fifty MSS. of articles which were available for publication on January 1, 1922. A few of these have since been withdrawn by their authors, in the hope of securing earlier publication elsewhere. In the case of some others, some abridgment has been suggested by the Board of Editors, in order to make it possible to publish as many of these articles at as early a date as possible. The Executive Committee, as authorized at the New Orleans meeting, is now considering the feasibility of including advertising in the JOURNAL, as a possible means of increasing the funds available for printing. If this is done, it is hoped that the JOURNAL may be regularly issued twelve times each year, in such numbers of pages as will permit the prompt publication of papers received.

The present editor pledges his best endeavors to promote prompt and adequate publication of all matters which are appropriate to the pages of the JOURNAL, and urges the hearty cooperation of the officers and members of the Society to this end.

NOTES AND NEWS.

Professor C. A. Michels, formerly of the North Dakota Agricultural College, is now in charge of the teaching in Field Crops in the Department of Agronomy at the Massachusetts Agricultural College. J. B. Abbott is Extension Specialist in Soils and Crops, and M. O. Lanphear has been added to the same Department as resident instructor.

Dr. Wm. Frear, Vice-Director and Chemist at the Pennsylvania Agricultural Experiment Station since 1887, died suddenly of heart failure, at his home in State College, Pa., during the night of Friday, January 7, 1922. Dr. Frear was widely known for his research work in agricultural chemistry and in connection with the development of food definitions and standards.

CORRECTION IN THE DECEMBER ISSUE.

The graph presented as Fig. 19, on page 346 of the December (1921) issue of the JOURNAL was accidentally printed upside down. In order that the matter should be properly shown, the diagram should be rotated thru an angle of 180°.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 MARCH, 1922 No. 3

SOME OBSERVATIONS ON THE BEHAVIOR OF BEARDED AND SMOOTH WHEATS[1]

BY A. E. GRANTHAM.[2]

In our work at the Delaware Station during the past twelve years considerable attention has been given to the testing of varieties of wheat. An effort was made to analyze more carefully some of the causes for the difference in yield of the varieties, particularly with reference to bearded and smooth wheats. As an outcome of this work it was found that the bearded wheats tiller somewhat more freely than the smooth, as was reported in Bulletin No. 117 of the Delaware Station. Following up this same work it was shown in Bulletin No. 121 entitled, " Wheat Investigations — Varieties," that the bearded wheats in previous tests averaged 3.3 bushels more than the smooth.

In studying varieties of wheat, it has been the custom to grow them on fertilized and on unfertilized land the same season. Even on the fertility plats where different carriers of plant food were applied, two varieties were grown on each plat, so that careful attention could be given to the variation which might occur between these two types. Our special investigations on wheat have given us the opportunity not only to compare the tillering habit and yield of wheat, but also to note the difference in quality. As a measure of the difference in quality, we have adapted the method of weight; that is, the relative quality of two varieties as indicated by the number of kernels required to weigh 10 grams. These were always taken from the ungraded grain.

[1] Read at the Chicago meeting, November 11, 1919. Received for publication, May 14, 1921.

[2] Formerly agronomist, Delaware Agricultural Experiment Station.

The results given in this paper have been secured in various ways

TABLE 1.—*Effect of fertilizers on the size of kernel in bearded and in smooth wheat. 1912 and 1916.*

Number varieties.	Number kernels in 10 grams. Fertilized.	No fertilizer.	Difference	Percent shrinkage
	1912			
Smooth — 34	330	422	92	21.7
Bearded — 26	310	343	33	9.6
	1916			
Smooth — 33	265	292	27	9.2
Bearded — 47	263	272	9	3.3

during the past 6 or 8 years. Table 1 shows the size of kernel on fertilized and unfertilized land, as the average of 60 varieties of wheat, 34 smooth and 26 bearded, for the year 1912. It will be noted that the average of the 34 smooth varieties was 330 where fertilizers were used. Where the land was untreated 422 kernels were required to weigh 10 grams, or a difference of 92 kernels additional to make the given weight where no fertilizers were used. In the same test the 26 bearded wheats gave 310 kernels per 10 grams on the fertilized land and 343 on the unfertilized, or a difference of 33 kernels more required for the given weight. It will be noted that about 3 times as many kernels were required to make up the difference due to lack of fertilizer in the case of the smooth. The same table shows the result of 80 varieties of wheat grown in 1916. Thirty-three of these varieties were smooth, which averaged 265 kernels per 10 grams under fertilizer, and 292, where no fertilizer was used. The 47 bearded varieties in the same test made an average of 263 kernels per 10 grams on the fertilized land and 272 for the untreated. In this case there were 3 times as many kernels required to make up the deficiency in the case of the smooth wheat as there were of the bearded.

Table 2 gives the average number of kernels in 10 grams for five varieties of bearded wheat and five varieties of smooth grown with and without fertilizer, during the years 1911 and 1912. In the case of the fertilized wheats the average is the result of 6 fertilized plats each season, and the untreated the average of four plats. The difference in number of kernels between the treated and untreated land in the bearded wheat was 41. In the case of 5 smooth wheats the difference was 72. Thus showing that the smooth wheats were more seriously affected by lack of fertilizer than the bearded.

TABLE 2.—*The variation in the size of kernel as affected by fertilizers in ten varieties of wheat. 1911 and 1912.*

	Varieties.	Kernels in 10 grams. No fertilizer.	Kernels in 10 grams. Fertilizer.	Difference.	Percent shrinkage.
Bearded	Farmers' Friend	320	271	49	15
	Gypsy	422	382	40	9
	Lehigh	339	299	40	12
	Turkey Red	437	405	32	7
	Velvet Chaff	425	378	47	11
	Average	388	347	41	10
Smooth	Dawson's Golden Chaff	482	384	98	20
	Early Ripe	393	312	82	20
	Fultzo-Mediterranean	402	371	31	7
	Gold Coin	478	379	99	20
	Mealy	502	449	53	10
	Average	451	379	72	15

Table 3 gives the results secured from planting two varieties of wheat, one bearded and the other smooth, on fertilized and unfertilized land, seeded at intervals of one week from September 17 to October 29. The smooth variety was the Red Wave, and the bearded, the Miracle. The fertilizers have a decided effect upon the quality of the grain and it will be noted that the quality of the smooth wheat deteriorated more rapidly with the later dates of seeding than did the bearded, particularly where no fertilizer was used. The uniformity of the size of kernel of the bearded variety where fertilizer was used is significant. This is in strict accord with other findings in our work that the bearded wheats seem to have the capacity for utilizing the plant food to better advantage, particularly where this material is not so rapidly available. This is shown by the more uniform quality of the bearded wheat under different dates of seeding where no fertilizer was used.

TABLE 3.—*The effect of time of seeding and fertilizers on bearded and smooth wheats.*

	Number of kernels in 10 grams.			
	Fertilizer.		No fertilizer.	
Date of seeding.	Bearded.	Smooth.	Bearded.	Smooth.
September 17	234	340	354	442
September 24	236	362	405	483
October 1	247	351	380	514
October 8	245	338	427	515
October 15	269	323	484	466
October 22	315	425	464	637
October 29	317	420	552	604

The question may naturally arise as to the average size of kernel of the varieties under question. Under normal conditions there is very little difference in the size of kernel between the two. For example, graded grain of either variety will run about the same number of kernels per given weight.

In studying this table it is well to note the extreme variation which occurs in the bearded and in the smooth variety under the different dates of seeding. This gives some idea of the spread in quality. For example, the smooth wheat without fertilizer ranged from 442 to 637 kernels in 10 grams. The bearded ranged from 354 to 352. It should be borne in mind, however, that the quality of the smooth wheat was much lower even at best than that of the bearded. Where the two were fertilized the smooth shows a variation of 323 to 425, a range of 102, while the bearded wheat under fertilizer shows a range of 234 to 317, a range of 83 kernels, altho the heaviest kernels of the bearded numbered 234 in 10 grams, as compared with 323 for the smooth under the same conditions.

The preceding tables indicate that fertilizers play an important part with reference to the quality of the grain, and that the bearded wheats seem to respond to it more rapidly than do the smooth.

TABLE 4.—*Effect of fertilizers on the size of kernel in wheat. 1919.*

Treatment.	Number kernels in 10 grams.		Difference.		Percent.	
	Bearded.	Smooth.	Bearded.	Smooth.	Bearded.	Smooth.
Nitrogen	343	684	117	416	51	150
Phosphoric acid	344	496	118	228	51	81
Potash	340	380	114	112	47	40
Nitrogen and phosphoric acid	337	552	111	284	47	102
Phosphoric acid and potash	245	268	19	......	7	......
Nitrogen and potash	287	400	61	132	26	17
Nitrogen, phosphoric acid and potash	226	283	......	15	......	5
Nothing	347	514	121	248	51	92

Table 4 gives the size of kernel for a bearded wheat, Rudy, and a smooth wheat, Leaps Prolific, for the year 1919, with both varieties grown under the various treatments indicated. From this table it will be noted that the best quality of the bearded wheat was 226 under complete fertilizer. The poorest quality was 347 on the check plat. In the case of the smooth wheat the best quality was on the plat receiving phosphoric acid and potash, 268 kernels as compared with 684 where nitrogen alone was used. It will be noted that wherever nitrogen was used (unless supplemented by phosphoric

acid and potash) the kernels, especially in the case of the smooth wheat, were lessened in quality. This is in accordance with the facts commonly noted, that an excess of nitrates will often cause wheat to shrivel badly. The significant factor of this experiment is that the spread in quality of the bearded wheat was far less than that in the case of the smooth. The column headed "difference" represents the difference between the highest quality wheat of both bearded and smooth as compared with that of the other treatments. Thus 117 under nitrogen, represents the difference between 226 and 343.

TABLE 5.—*Size of kernel from bearded and smooth wheats taken on Delaware farms. 1919.*

Number of kernels in 10 grams

	Bearded.	Smooth.
	250	574
	284	512
	292	440
	308	368
	330	408
	260	380
	356	432
	268	346
	286	482
	266	358
	254	300
	298	392
	256	324
	272	396
	240	408
	312	412
	232	384
	250	436
	400	546
	290	404
	298	358
Average	285	412

Table 5. Soon after harvest during the past summer (1919) there was a wide comment that the wheat was not well filled, altho the production of straw was greater than usual. The writer had the opportunity of visiting a large number of fields in various parts of the State from which he took samples, wherever possible, of bearded and of smooth wheats grown under the same conditions of tillage and fertilization. Table 5 shows the number of kernels per 10 grams of these samples of bearded and smooth wheats taken on the same farm, and sometimes from the same sheaf. The lower part of the table shows more or less miscellaneous samples, for example, where a bearded or smooth wheat was taken from adjacent

farms or in the same neighborhood. In only a few cases were the smooth wheats of as good quality as those of the bearded. In these few cases it appeared that the proper balance of plant food had been applied, which accounted for the better quality of the smooth kernels. Wherever an excess of nitrogen is applied it seems to affect the smooth wheats more adversely than the bearded.

SOME METHODS OF RECORDING DATA IN TIMOTHY BREEDING.[1]

Morgan W. Evans[2]

Certain methods of obtaining records, which have been used during the past few years in connection with timothy breeding experiments, are described in this paper to illustrate the advantage of substituting quantitative data for those which are merely the results of general observations. For several years past the writer has been engaged in timothy breeding investigations, at the Timothy Breeding Station which is conducted cooperatively by the United States Department of Agriculture and the Ohio Agricultural Experiment Station, at Elyria, Ohio. The breeding of timothy is a phase of experimental agronomy which is of very recent development. Many of the methods which are used in timothy breeding, consequently, have to be originated as the work progresses.

Method of Comparing Different Varieties of Timothy.

One of the important phases of work in the breeding of timothy, as well as of any other crop, is the comparison of different selections or varieties with one another. In the comparison of different varieties of timothy, one of the things to be determined is the relative yields of hay which they will produce. As the result of a number of studies by different investigators, working with various field crops during the past ten or fifteen years, quite reliable methods have already been developed for growing the varieties in experimental test plats, and for obtaining records of the hay yields in these plats. But such matters as the time of blooming, maturity, number of green leaves on plants, and length of stems, however, are likely to be recorded differently by different observers, unless definite methods are adopted.

[1] Contribution from the Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for Publication, December 30, 1920.

[2] Assistant Agronomist, Bureau of Plant Industry.

Time When Timothy Plants are in Bloom and Mature.

The earliness or the lateness of the plants of different varieties is an important characteristic to be studied when they are compared. Until the method described in the following paragraphs was adopted there was no way by which the degree of earliness or lateness of different varieties of timothy could be accurately measured.

The earliness or lateness of a variety of timothy is indicated quite largely by the time when the plants are in bloom and mature. In order to get definite records of the time when the plants are in these stages of development it is necessary to have definitions of the conditions of the plants when they are in bloom or mature. The term *plant* as related to timothy, is applied to all the shoots which have grown from a single seed, or from the detached vegetative part of another plant. Before the various stages of bloom can be defined for the plant, it is necessary to have a definition of a head in full bloom. The following one has been used:

A timothy head is in full bloom when flowers are in bloom throughout two-thirds or more of its entire length.

When a timothy head is passing out of the stage of full bloom, the boundary between the part of the head where the flowers are in bloom, and where they are not in bloom is usually not as well defined as on heads which are just coming into full bloom. The head can be considered in full bloom, however, when flowers in bloom are distributed over two-thirds or more of its total length, whether the area over which the flowers are blooming is, or is not, continuous.

The time during which a timothy plant is in bloom has been divided into four periods as follows:

Early Bloom. *A timothy plant is in early bloom from the time that the first flowers have bloomed until it is in full bloom.*

Full Bloom. *A timothy plant is in full bloom from the time that 25 per cent of all heads are in full bloom, and 25 per cent or more additional heads have begun to bloom, until 25 per cent of all heads are past full bloom and 25 per cent or more additional heads are past bloom through some portion of their length.*

Late Bloom. *A timothy plant is in late bloom from the time that it has passed full bloom until it is in very late bloom.*

Very Late Bloom. *A timothy plant is in very late bloom when all of the main crop of heads are entirely past bloom, and only a few small late heads, usually on short culms, remain in bloom.*

The condition of a timothy plant when mature is explained in the following definition:

A timothy plant is mature when all of the glumes have become straw

colored on 25 per cent of the heads, and more than half of the glumes have become straw colored on 50 per cent or more additional heads.

The records of blooming and maturing have usually been obtained from plants growing at a distance of 2.5 feet apart, in rows which are 3.3 feet apart. When the plants are in bloom, the records can can best be obtained early in the morning, as it is more difficult to obtain accurate records after the filaments of the anthers have become wilted by the sun and wind. When the plants are maturing, the records can be obtained at any time of the day. While records are made of each plant when it is in early, full, and late bloom, on each day when the plants are in bloom, the records of the time of full bloom only have been used when the data have been compiled. From the total number of plants in each plat, and from the number of plants in these plats which are in full bloom or mature on different dates, the percentage of plants in full bloom or mature on each date can be readily calculated. To illustrate the use of these definitions, our records show that in 1917 in a plat of timothy, No. 6162,[3] half of the plants were in full bloom 3 days earlier and matured 4 days earlier than were an equal proportion of the plants in a plat of ordinary timothy with which it was compared. In another plat, of selection No. 6779, half of the plants remained in full bloom 5 days later, and matured 6 days later than the ordinary timothy.

When there is any doubt whether a plant should be recorded in early bloom or in full bloom, it has been the practice to classify it in early bloom. Likewise, if there is some uncertainty as to whether a plant is in full bloom or in late bloom, it is classified with the plants in full bloom. In other words, no change is made in the daily records of a plant, from the stage of bloom in which it has been during the days immediately preceding, if there is any doubt whether the change should be made.

In each season, there are usually one or more days during the blooming period, when, because of unfavorable weather conditions, timothy flowers do not bloom. On such days it has been the practice to make no record at all of the condition of the plants.

Experience has demonstrated that the relative difference in the time of blooming, and of maturing, of any two varieties of timothy, one of which may be early and the other late, is approximately the same. In comparative studies of different varieties, therefore, records of the time when the plants are in bloom may be sufficient;

[3] The numbers used here belong to a series of numbers which have been assigned by the Office of Forage-Crop Investigations to different selections of timothy and other crops.

the records of the time when the plants mature can often be omitted, with no serious loss of data.

Through this system of recording notes it has been possible to present definite information in regard to how early or how late the timothy plants in plats of selections Nos. 6162 and 6779 bloomed and matured. By the same method it would be possible to obtain exact comparisons of these selections with other selections; or to determine accurately whether the relative times of blooming and maturing of plants of selections Nos. 6162 and 6779 are the same in any other season as they were in 1917. Without this system about all that it would have been possible to state, in regard to the earliness and lateness of the selections, would be that one bloomed and matured somewhat earlier and the other somewhat later than ordinary timothy.

One test of the value of any scientific method is its accuracy when employed by different persons working under various conditions. Obviously, it would not always be possible to determine whether a timothy plant should be considered in early bloom, or in full bloom, with the same exactness that a quantitative determination can be made in a chemical laboratory. Nevertheless, it has been found that the percentages of plants in early, full, or late bloom can be determined very closely. It is only a small proportion of the plants which an experienced observer has any difficulty in classifying. If a timothy plant is so nearly on the border line between the stage of early bloom and full bloom on any particular date, that two observers might classify it differently, usually by the next day when the flowers are in bloom, the numbers of flowers in bloom will have increased to such an extent that there will be no doubt about the plant being in full bloom.

In 1919 two observers, working independently, made records of the number of plants in full bloom in the same row plat of timothy.

TABLE 1.— *Percentage of timothy plants in full bloom, on different dates in 1919 in a row plat of 20 plants propagated vegetatively from the original plant of No. 9400. Results obtained by two observers working independently.*

Date.	Percentage of plants in full bloom as determined by observer.	
	A.	*B.*
July 1	90	95
2	90	95
3	95	95
8	25	30
10	10	5
11	5	5

These records are presented in Table I. This table shows that while there was a slight difference in the results, the general character of the curves that could be plotted from these data would be essentially alike. Results obtained by other observers in 1917 and 1918, indicate that the records obtained from the same plats by two experienced observers may be even more nearly identical than those presented in Table I.

THE RELATIVE NUMBER OF GREEN LEAVES ON PLANTS OF DIFFERENT VARIETIES.

Records which show how much earlier or later the flowers bloom and seeds mature, on plants of one variety of timothy than on the plants of another, do not usually tell the complete story of the relative earliness or lateness of the two varieties. It has been observed during the early summer months that, on any particular date, a larger proportion of the leaves are green on the plants of some selections than on others. In order to get accurate information in regard to this characteristic, a method has been developed for determining the number of leaves with blades which are either entirely or partially green, per unit of area, in broadcast plats or meadows of different varieties.

All stems were collected daily from June 25 to August 5, 1919, from two typical areas each 6 by 36 inches, in duplicate broadcast plats of ordinary timothy and of timothy No. 3937. Four sets of stem of plants of each variety were therefore examined each day. The samples were taken to the building on the Timothy Breeding Station and each was separated into two groups of stems — those with heads, and those on which no heads had developed. A record was then made of the number of stems of each type, and of the number of leaves with blades either entirely or partially green on each stem. It has been the practice to consider a leaf blade partially green as long as the tissue remains green across the entire width of the blade at its base, or as long as there is green tissue partially across the blade extending for one inch or more above the base of the blade. From these records, the average number of entirely and partially green blades per stem on each date was calculated. Then, in each of the duplicate plats of the two varieties, three typical square-yard areas were selected and a count was made of the number of stems with and without heads in each area. From the data obtained the total number of leaves with entirely or partially green blades per square yard, on each date, in plats of both varieties, was calculated in the following manner: The average number of stems with heads per square yard was multiplied by the average number

of leaves with entirely or partially green blades on stems with heads on any particular date; the average number of stems without heads per square yard was multiplied by the number of entirely or partially green leaf blades on these stems on that date; the total number of entirely and partially green leaves per square yard was obtained by adding the two products. The records obtained in 1919 are presented graphically in Figure 1.

Fig. 1—Graph showing number of leaves with green or partially green blades, in typical square-yard areas in plats of ordinary timothy and of No. 3937, on different dates in 1919.

These records not only show that there may be more green leaves in a plat of one variety than of another, but also just how many more green leaves there are per unit of area in the plat of one variety than of the other. Considerably more time is required to obtain these records than those showing the degree of blooming and maturity. The time required for determining the relative numbers of green leaves in plats of different kinds of timothy could probably be reduced, and at the same time the efficiency of the method might be maintained or increased, if samples were collected at 5-day intervals instead of daily, and if somewhat more than two samples per plat were collected on each date. If from three to five samples had been

collected on each date in 1919, the curves in Figure 1 would probably show less irregular variations from day to day. If the number of samples were increased, it is possible that the size of the area from which they are collected could be made somewhat smaller than 6 by 36 inches, and thus the time required to obtain the records would be further reduced.

Length of the Stems of Plants of Different Varieties of Timothy.

One of the conspicuous differences between some of the selections and varieties of timothy which have been studied, is that the stems of the plants of some are longer than those of others.

Timothy plants growing in cultivated rows produce a large number of stems. In order to determine their exact average length, it would be necessary to measure the length of all the stems in each row. This work would require so much time that the method would probably not always be a practicable one. It has been observed that in cultivated rows most of the stems of any one timothy plant usually grow to approximately the same height. Therefore, if the longest stem of each plant in a row is measured, from the surface of the soil to the tip of the head, the average length of these longest stems will quite nearly represent the average length of the stems of all plants in the row.

Records of the lengths of the longest stems of the plants in two row plats of timothy Nos. 6824 and 6839, and in one row plat of ordinary timothy, were obtained in 1917. These plats were located near one another, on uniform soil, and the plants had been grown under the same cultural conditions. This information is presented in Table II, which shows that the average length of the stems in the plat of ordinary timothy was slightly greater than in the plat of No. 6824, and was considerably less than in the plat of No. 6839.

Table 2.—*Average length of the longest stem of plants in row plats of timothy.*

	Inches.
Ordinary timothy	43.5
Timothy No. 6824	42.9
Timothy No. 6839	51.8

If these or other similar records are represented by graphs, they may show that the lengths of the stems of some selections are more uniform than the lengths of the stems of others. By calculating the average deviation from the mean length of the longest stems of the plants in each one of the plats, it would be possbile to express in quantitative terms the degree of uniformity of the lengths of the longest stems of plants of the different selections.

SUMMARY.

In timothy breeding, which is a comparatively new phase of experimental agronomy, standard methods have yet to be worked out and adopted. Several methods which have recently been developed for making comparative quantitative studies of different selections or varieties of timothy are described in this paper.

Through the use of certain definitions which describe timothy plants in different stages of bloom and maturity, it has been possible to obtain accurate records of the time when the plants of different selections or varieties of timothy are in bloom and mature.

A system of counting the number of leaves with partially or entirely green blades has been developed, by which the relative numbers of green leaves, per unit of area, on different dates in broadcast plats of different kinds of timothy, can be accurately determined.

By measuring the longest stem of each plant growing in cultivated row plats of different selections or varieties of timothy, it is possible to obtain data which show not only the relative lengths of the stems of the plants in the different plats, but which also show the relative degree of uniformity in the lengths of the stems of plants in the plats in which measurements are made.

SUNFLOWER STUDIES[1]

P. V. CARDON.[2]

I — VARIATION IN THE "MAMMOTH RUSSIAN" VARIETY.

The results of cultural experiments with sunflowers, as conducted since 1915 by the Montana Experiment Station, show the "Mammoth Russian" to be better as regards acre-yield of silage than any other variety tested. However, it is plain to all observers that there is little uniformity in the type of plants produced from the commercial seed of this variety and the possibility of developing superior strains must have appealed to everyone who is interested in selection for the improvement of the sunflower crop.

In Montana, a particularly urgent need for improvement in the sunflower crop arises as the result of varied conditions of soil and climate. In the high plateau regions of the western part of the state, where sunflowers seem to be especially well adapted, no seed can be matured because of the short growing season. This condition makes necessary the importation of seed from other regions. Good sun-

[1] Contribution from Agronomy Department, Montana Agricultural Experiment Station, Bozeman, Mont. Received for publication, April 17, 1921.

[2] Agronomist.

flower seed can be produced under irrigation in the lower altitudes of eastern Montana, and it may be possible to establish in that region seed supplies to meet the requirements of western Montana farmers. The problem, however, is to get a strain to satisfy both the seed grower of the east and the silage grower of the west.

The difficulty encountered in harvesting sunflowers which are so tall as they grow under irrigation in Montana, affords another practical reason for undertaking improvement work with sunflowers. A high producing strain possessing a relatively low habit of growth, which would facilitate the harvest of the crop by permitting free use of the corn binder, would be especially desirable.

It was in recognition of the foregoing requirements that the Agronomy Department of the Montana Experiment Station began its selection work with sunflowers in the spring of 1920. Although the results of only one season are available, they are suggestive of the possibilities with this crop.

For the reasons already given, the "Mammoth Russian" variety was used in this preliminary work. Identical plantings were made under irrigation at Bozeman, and on dry land at Huntley, Moccasin and Havre, each point being representative of a different combination of soil and climatic conditions. In each planting, there were 144 hills (checked) 3 feet apart, making a plot 39 feet square. Only the 100 plants inside the square were studied, the 12 outside plants on each side of the square being treated as controls. Since the 100 plants were equi-distant and all under practically the same environmental influences, it was assumed that their habits of growth were entirely the result of inherent tendencies. Seed from the same commercial lot was used at all four points, and enough seed sown in each hill to insure the presence of at least one plant. Later, only one plant was left to develop in each hill.

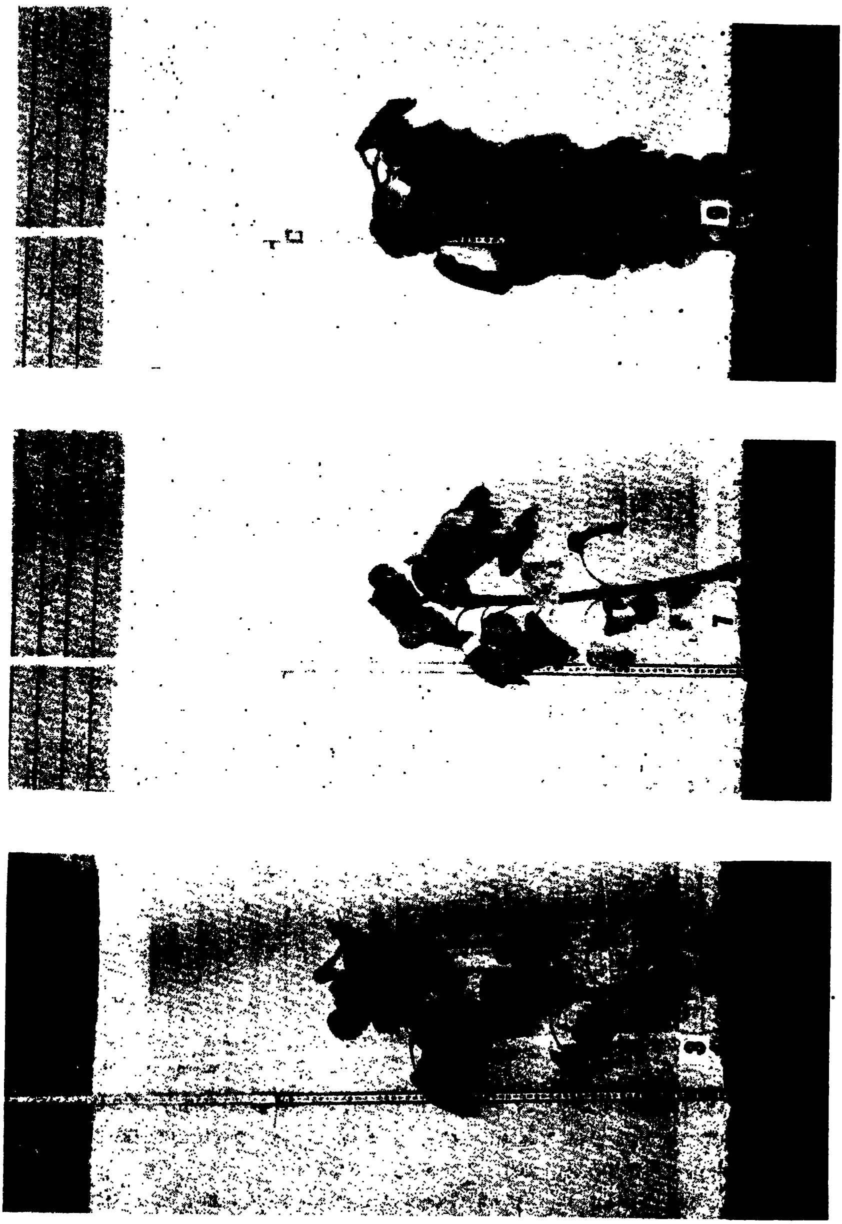
The plantings at Moccasin and Havre were seriously injured by drouth, but at Huntley and at Bozeman it was possible to make some interesting comparisons, as shown by the photographs presented herewith.[3] See Plates I, II and III.

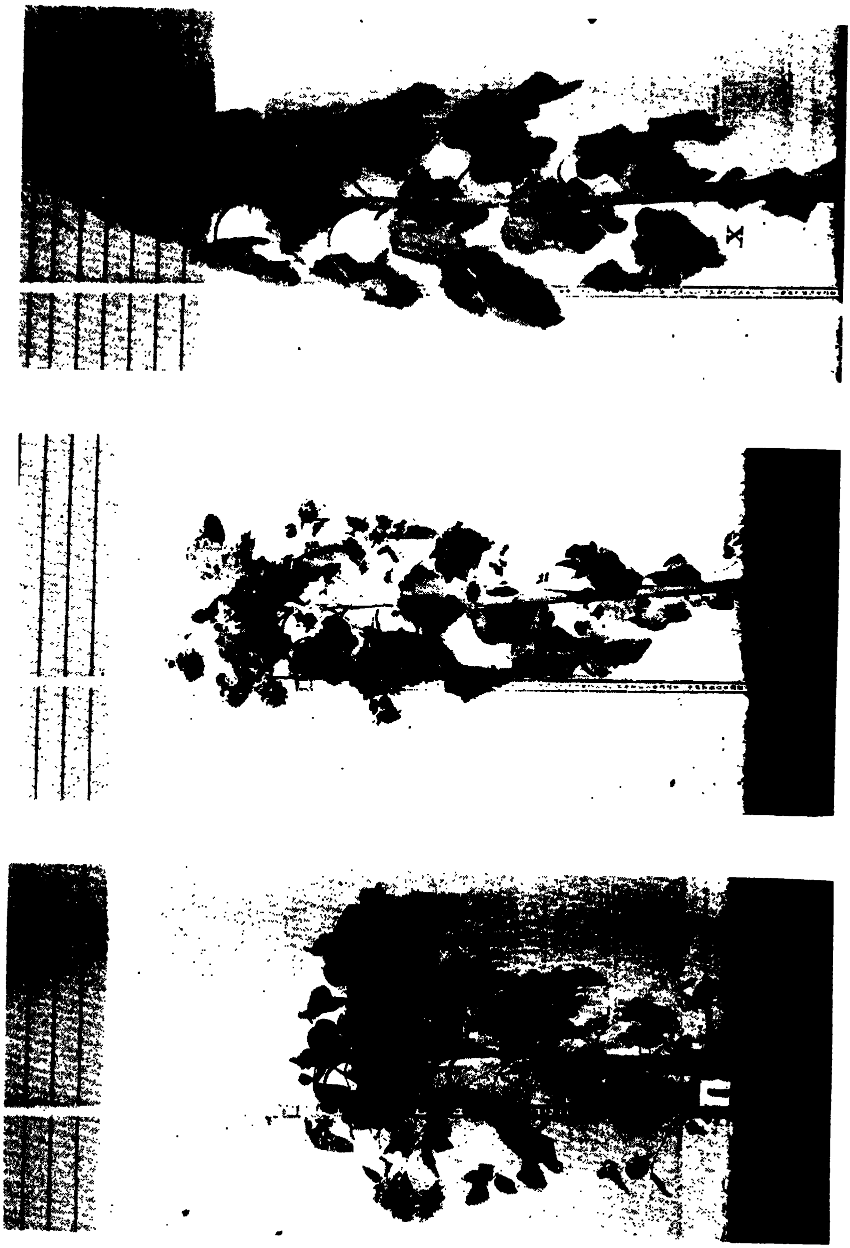
At Huntley, on September 7, when most of the plants were in full bloom, 10 different types were distinguished. Later, it was found that two of these (No. 3 and No. 4) each comprised at least two sub-types, distinguishable on the basis of either seed color or earliness.

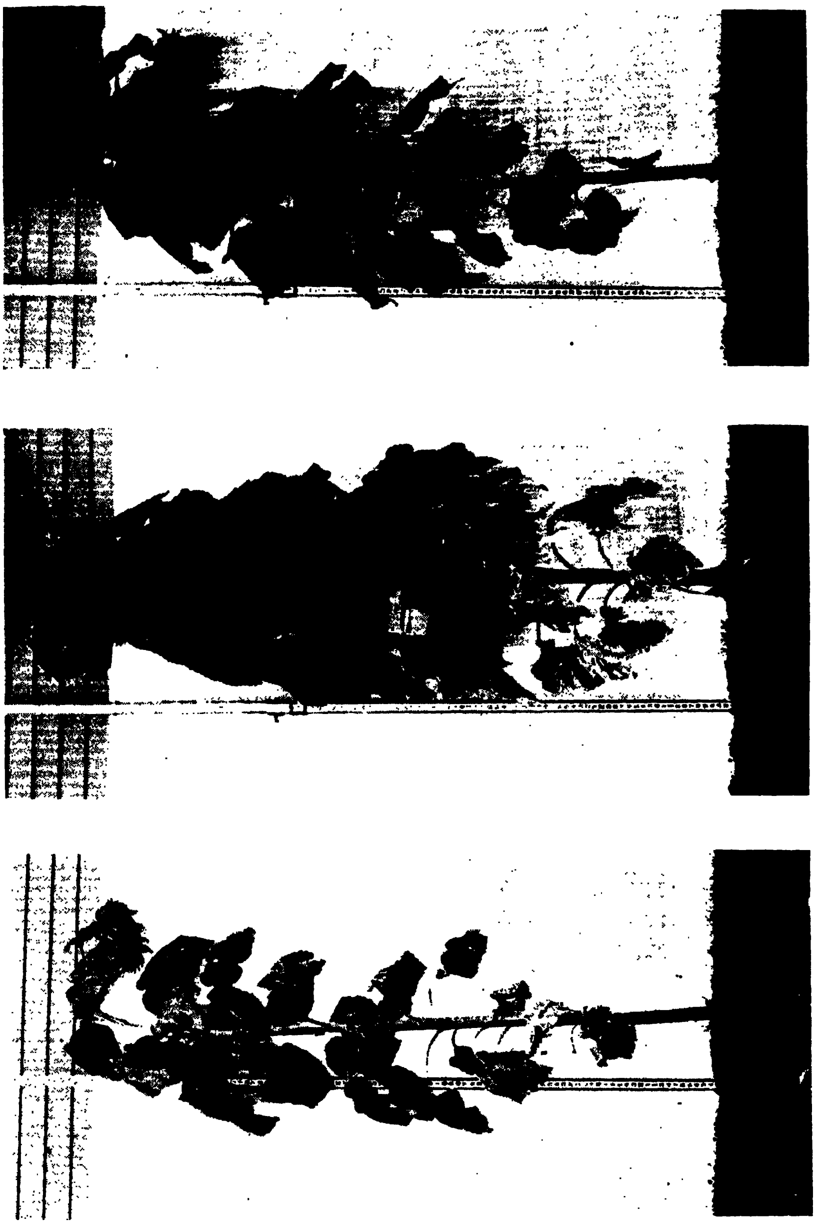
Following is a brief description of each type, with the percentage of plants it included, and a note as to maturity.[4]

[3] All of the photographs accompanying this article were taken by J. B. Nelson, Field Superintendent, Agronomy Department, Montana Experiment Station.

[4] The writer is indebted to A. E. Seamans, Assistant in Dry Land Agriculture, Huntley Experiment Farm, for his helpful interest in these studies.







Type No. 1 (6 per cent) — Wild in appearance; branched, bearing heads on both primary and secondary branches; low growing and somewhat spreading; leaves mostly small, except on main stalks; stalk slender; plant light to yellowish; fully matured October 23; seeds generally small, striped to dark gray in color; (Plate II-A.)

Type No. 2 (1 per cent) — Single stalk, upright, about 6 feet tall; very broad leaves with relatively smooth margins; head of medium size with sharp crook in stem near base of head, giving "gooseneck" appearance; dark green; early maturity; seeds black with few white stripes.

Typė No. 3 (9 per cent) — Very distinct type and relatively early; closely resembles No. 2, except leaves are a little smaller, sharply serated and apex more acute; about six feet tall; leaves appear to be almost in whirls on lower part of stalk; mature October 23; seed color variable (a) black with occasionally a white stripe and (b) seeds white with fine black stripes; very early, but not valuable for silage. (Plate I-A.)

Type No. 4 (28 per cent) — Tall, single stalk; unbranched; late; leaves roundly broad and deeply serated; stalk fairly thick; color variable but mostly dark green; apparently two strains; (a) matured October 23, and (b) matured November 11. (Plate III-A.)

Type No. 5 (10 per cent) — Very similar to No. 4, except for small axilary branches; seeds dark; immature November 11.

Type No. 6 (8 per cent) — Similar to No. 5, but plant is bushier and branches longer; fully matured October 23; seeds variable in color, light and dark in different heads of same plant. (Plate II-B.)

Type No. 7 (25 per cent) — Resembles No. 3, except that stalk is inclined to droop in "sickle" shape. The stem seems to taper off from about center toward head, giving appearance of long slender neck. Leaves sparse on lower part of stalk — distinct from No. 3 in this respect. Fully matured by October 23; seeds variable in both color and shape — dark to striped, and short to long; early, but foliage too sparse for high yield of silage. (Plate I-B.)

Type No. 8 (11 per cent) — Resembles No. 4, except at top. Leaves more numerous than on No. 4; shorter internodes, giving "pine top" appearance to plant; only few mature seeds found on November 11; ideal for heavy yields, but too tall for ease in harvesting. (Plate III-B.)

Type No. 9 (1 per cent) — Closely approaches No. 7, except that leaves are more numerous and much broader; plant low-growing, single stalk; stalky, with approach to "sickle" neck; no seed matured. (Plate I-C.)

Type No. 10 (1 per cent) — Tall, approaching No. 4 in height and general appearance, but has head and leaf characters of No. 3, and tapering at top of stalk similar to No. 7; no seed matured. (Plate III-C.)

Eight of the types described at Huntley were easily distinguished among the irrigated plants at Bozeman; but at the latter place No. 2 and No. 5 were not represented, whereas X, an eleventh type, was discovered. This type is extremely tall and late; it was not yet in full bloom when killed by frost.

Viable seed was secured of all the earlier types except No. 2, and will be used in connection with a continuation of these studies.

II — EFFECT OF BAGGING SUNFLOWER HEADS.

Uncertainty as to whether sunflowers are normally self-fertilized led the writer to bag a number of heads during the season of 1920 and observe their behavior. The effect of bagging on fertilization was so pronounced as to be of special interest.

The first effect to be noted was the disturbance of the normal flowering habit. Ordinarily, the flowers on the sunflower head

variations were perhaps much more common than is generally supposed and that a careful search for them even among the old and well established varieties would be rewarded. Accordingly in the spring of 1920 small samples of seeds of maize were collected from several seed companies and from a number of the northern experiment stations. No attempt was made to include all of the varieties grown in the northern states nor all varieties listed by the different seed companies from whom samples were obtained. Only those which gave promise of maturing in the latitude of Ithaca were sought. In some cases several samples of the same variety, particularly in sweet and pop corns, were obtained from different sources. In all approximately 650 different samples were collected.

Since the maize plant is ordinarily cross pollinated any commercial variety even after years of more or less careful selection consists of a hybrid and mechanical mixture of different strains. Recessive variations, though too weak to survive when homozygous, nevertheless may be carried along in a heterozygous condition and appear occasionally in an ordinary field of corn. When a plant which is heterozygous for such a character is selfed the variation appears in the immediate progeny in numbers approximating twenty-five percent if the character depends upon a single hereditary gene. It was, therefore, expected that by selfing a number of plants from each of the different lots of seed collected some of the ears produced would show such heritable variations as were present in a heterozygous condition in the original seed. From fifteen to thirty seeds of each sample were planted with the intention of selfing at least five plants of each lot. A severe drought immediately after planting resulted in a poor stand in some cases which, together with the necessity of caring for other cultures during the pollinating season, prevented the successful completion of the original plan. However, 2110 self pollinated ears representing 468 of the 650 lots of seed were obtained.

In genetic studies with maize, seed and seedling characters are especially desirable since individuals possessing such characters may be grown in large numbers in hybridization experiments with the minimum expense of time, labor and space. Apparently no unknown seed characters have appeared among these self pollinated ears, although this point cannot be determined definitely, of course, until certain genetic tests have been made. Defective seeds (2)[4], however, were rather common, appearing on 67 of these self pollinated ears.

[4] Reference by number is to "Literature Cited," p. 78.

During the present winter seedling tests have been made in the greenhouse of 1872 of these selfed ears, and a surprisingly large number of seedling variations found. Approximately fifty kernels from each ear were planted and the seedlings examined when they were about three weeks old.[5]

A summary of the observations made on the 1872 families from selfed ears shows that 681, or 36.4 percent, contained seedling variations of some kind. In most of these families a single variation was involved but in others two or even three were sometimes found. Of the 1872 families, 136 or 7.3 percent, contained morphological variations of various kinds, such as dwarfs, spearlike seedlings most of which are apparently completely enclosed within the coleoptile and soon perish, and various forms of twisted and cut stems or other fasciations. In most cases these morpholoigcal variations appeared in numbers approximating twenty-five percent and probably are simple recessives. Dwarfs of various kinds were most numerous, occurring in 23 different families, most of which were unrelated.

By far the most numerous seedling variations were chlorophyll deficiencies. These included white seedlings and white and yellow virescents found in 201 families, pale greens in 107 families, yellow and white striped or streaked plants in 58 families, and a miscellaneous group of chlorophyll characters in 164 families. In addition 45 families contained plants with a distinct waxy or glossy appearance of the leaves, in 44 of which about 25 percent of the plants were glossy, while in another family all of the plants showed this characteristic.

It is proposed to examine the progeny of each of these 1872 selfed ears for mature plant and ear characters by making a second planting in the field. As many variations of mature plant characters as of the seedlings are hardly to be expected, since such abnormalities are much more apt to be eliminated particularly from the older and well established varieties thru the usual process of seed selection. However, it seems probable that some variations will be found and doubtless in sufficient numbers to make a search for them worth while.

The number of variations so far found in this survey, as well as their frequency, is surprisingly large. Particularly is this true when it is recalled that only relatively few plants in each lot of seed were selfed. The largest number of plants selfed in any lot was fifteen and from each of only 144 lots were four or more selfed ears obtained.

[5] Most of the pollinating as well as the detailed work involved in making these seedling tests was done by Mr. Fred H. Dennis to whom the writer is indebted.

These variations must be very numerous when chance selection of so few plants reveals their presence in so great a frequency.

THE BEARING OF VARIATIONS IN MAIZE UPON YIELD.

By far the greater number of variations that have been found in maize are simple recessives. Linkage studies that have been made show that the factors concerned are scattered well thruout the entire chromosome complex. With the exception of aleurone, pericarp and endosperm colors, as well as most of the plant colors, plants homozygous for these various characters usually are much less vigorous than the normal. Most of them would probably not survive under natural conditions. This is especially true in respect to many of the chlorophyll variations and several of the morphological abnormalities. White seedlings being devoid of chlorophyll do not survive the seedling stage. Virescents, either white or yellow, are matured only with difficulty and those which do survive are much smaller and weaker than normal greens.

The germination of the extreme dwarfs under field conditions is usually poor, apparently on account of the fact that the short plumule has difficulty in pushing thru the surface of the soil. The semi-dwarfs usually germinate and grow satisfactorily; but as their name indicates they do not make the same growth and hence yield less of both grain and stover than normal plants. All of these weaklings undoubtedly have some effect on yield—how much it is difficult to say.

The corn grower has long been told that the first prerequisite of a good crop is a full and even stand. He has been advised carefully to test the germination of his seed in order that a full stand of vigorous and healthy plants may be obtained. Manufacturers of corn planters have paid particular attention to the development of machines designed to drop the kernels with a high degree of accuracy. Butt and tip kernels of seed ears are generally discarded because of their irregular size and shape and frequently the remaining kernels are graded for use with different sizes of planter plates in order to obtain an even distribution in planting. It is probable, however, that the well known response of the maize plant to its environment by the development of more tillers where the stand is below normal (5) and the partial compensation for missing hills by increased growth of surrounding plants (3) may help materially to recover such loss from a poor stand as would be caused by the demise of these weaklings. Other variations, however, such as barren stalks; ramosa ears; crinkly leaves; some of the semi-dwarfs, like the pistillate plants tassel-seed and tassel-ear; or some of the chlorophyll variations, which, although not lethal, cause a marked

weakening of the adult plant; if numerous enough would undoubtedly reduce the yield.

No data are available to show how frequently such abnormalities occur under field conditions. That they occur in the heterozygous condition to a considerable extent in many varieties is evident from the results of the survey of some of the northern corns reported in this paper. It is probable that a careful study of fields would reveal their presence to a much greater degree than is generally supposed. But whether they occur in sufficient numbers materially to affect the yield may be a debatable question. The important consideration would seem to be whether plants heterozygous for these abnormalities are less vigorous than the homozygous normals. If they are, then these variations undoubtedly decrease yields.

Inbreeding experiments with animals, as well as the experience of animal breeders, have shown that when accompanied by careful selection of the most vigorous offspring inbreeding may sometimes result in increased size and vigor. Self fertilization in corn results generally in a marked loss of vigor with the isolation of quite distinct, though fairly uniform, lines or biotypes. Crossing such inbred strains restores the vigor lost by inbreeding, sometimes to a point even beyond that of the original variety, but it generally declines again in subsequent generations. This increased vigor of F_1 hybrids, or heterosis, has been accounted for by Jones (1) on the hypothesis of dominance or partial dominance of linked growth factors. Loss of vigor thru inbreeding, as well as the isolation of different biotypes, is assumed to be due to the sorting out of different sets of these growth factors. It is assumed that there are ten groups of these factors in each parent and that the dominant allelomorphs of some factor pairs are in one parent while others are in the other parent. The F_1 contains all of the dominant genes for growth of both parents but on account of linkage only rarely if ever are all to be found together in subsequent generations. The genes responsible for these recessive abnormalities are also involved in the general factorial complex for growth. Since they are weaklings their removal by means of selective inbreeding and their replacement by the allelomorphs for the normal condition would be expected to add to the sum tota of the action of other growth factors. If dominance were complete in all cases these recessive abnormalities, when heterozygous, should in themselves have no effect upon growth, but anything less than complete dominance would reduce the vigor to a corresponding extent.

On the whole it would seem reasonable to expect that if a variety could be completely rid of the hereditary factors responsible for these inferior characters and still retain a good set of other growth

factors it would be more vigorous and hence yield better than originally. Lindstrom (4) questions whether the latter can be done. There is reason to believe, as he points out, that the genes for these abnormalities are scattered well thruout the chromosome complex. The same is doubtless true in respect to those elusive factors for growth, whatever they may be, upon which size and yield may depend. Therefore, he reasons that when one isolates and eliminates these inferior types by inbreeding one also eliminates some of the better factors for growth that are correlated with the unfavorable ones in inheritance. This, of course, would be true if these unfavorable factors were usually or always closely or completely linked with the better growth factors. It is difficult, however, to see why they should be linked more often with good growth factors than with poor ones and why, on the average, as many poor growth factors as good ones should not be eliminated along with the recessive allelomorphs of these abnormal or inferior characters by selective inbreeding. Furthermore, while some gametes would contain probably all of the other growth factors in a particular chromosome in which the gene for some abnormality is located, others thru the process of crossing over would contain quite different factorial complexes. Such an interchange between homologous chromosomes should result, sometimes at least, in the elimination of an inferior character without disturbing greatly the remaining factorial complex. The matter of finding such cases would seem to depend upon the number of inbred strains one could produce and the number of combinations between different inbred strains one could test. While one could hardly expect to eliminate all of the inferior growth factors and combine all of the superior ones of even two varieties thru inbreeding and subsequent crossing yet it should be possible by combining different lines from different varieties in double or even quadruple hybrids on a fairly large scale to find certain combinations of factors that would give better growth than any of the original varieties and which would remain fairly constant in subsequent generations.

LITERATURE CITED.

1. JONES, D. F. Dominance of linked factors as a means of accounting for heterosis. *In* Genetics 2: 466–479 1917.
2. ——————— Heritable characters of maize. IV. A lethal factor—defective seeds. *In* Jour. Hered. 11: 161–167. 1921.
3. KIESSELBACH, T. A. and RATCLIFF, J. A. Freezing injury of seed corn. Neb. Agr. Exp. Sta. Res. Bul. 16: p. 1–96. 1920.
4. LINDSTROM, E. W. Chlorophyll factors of maize. *In* Jour. Hered. 11: 269–277. 1920.
5. MONTGOMERY, E. G. Experiments with corn. Neb. Agr. Exp. Sta. Bul. 112: p. 1–36. 1909.

THE FIELD PROBLEM IN THE SOILS COURSE.[1]

A. B. Beaumont.[2]

The list of exercises for a standard course in soils recommended by the Lexington conference on soil teaching, June 23–25, 1920, contains one assigned problem in soil management. Due to the interest recently manifested by many in the improvement of the courses in soils and to a number of inquiries which we have received regarding our method of conducting the field problem, it was thought worth while to present to the readers of the Journal the manner in which the field problem in soil management is handled at the Massachusetts Agricultural College.

These field exercises, of which the ones listed below are a development, were first tried out on a comprehensive scale in the fall of 1919. We feel that while they are not by any means perfect and will doubtless undergo further change as our experience lengthens, they have been remarkably worth while and have come to be an essential part of the courses.

Our group of vocational agricultural students, who are at college for two years only, and of which we ordinarily have a class of 150 to 200, are given the following considerable verbal instructions. Sheet 1 is taken by the students to the operator of the farm to which they have been assigned, to serve as an introduction and to give official college approval of the project. Sheet 2 contains detailed directions for the student. Sheet 3 is also in possession of the student.

Sheet 1.

Massachusetts Agricultural College

Agronomy S-I.

Field Problem in Soil Management.

The students of the Massachusetts Agricultural College, who are enrolled in the two-year practical course as well as the disabled service men assigned to the college by the Federal Board are required, as part of their work in the study of soils and fertilizers, to become familiar with some particular farm and its problems of soil management.

The work will include an outline map of the farm and a study of the following problems:

[1] Contribution from the Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass. Received for publication May 23, 1921.

[2] Professor of Agronomy.

1. Moisture control; [illegible]
2. Methods of tillage.
3. The organic matter [illegible]
4. Requirements of the soil for lime.
5. Use of manure and fertilizers.

The undersigned students have been assigned to a certain area. It is hoped that farm owners may be willing to permit the students to go over their farm for the purpose of this work.

Sheet 2

Massachusetts Agricultural College

Agronomy S–I

Field Problem in Soil Management.

Detailed Directions for Procedure

I. Draw to scale of not less than 500 feet per inch a map of farm, showing boundaries of fields, location of buildings and areas of different soil types. Color as follows: green = water, black = poorly drained, blue = clay, brown = sandy loams, yellow = infertile sand or gravel.

Sample carefully each soil type to a depth of 7 inches, and also subsoil to a depth of 20 inches. Bring samples into laboratory for mechanical analysis and acidity test.

II. The report must cover:

1. Moisture conditions.
   How much land is now too wet to plow?
   How much might be tile-drained?
   Indicate on map possible location for mains and outlets.
   How much is likely to be drouthy as indicated by subsoil and vegetation?
   Describe topography; give amount and direction of slope.
   Is land stony?
2. Tillage.
   How much land plowed for this season's crops?
   How much fall and spring depth?
   How much sod and stubble?
   Type and make of plow used.
   Type of coulter used.
   Types of harrow used.
3. Organic Matter.
   Sod plowed under? How many acres?
   Cover crops and green manure? How many acres?
   Acres newly seeded. Time of seeding. Seed mixture.
   Acres in hay last year.
   Stock kept. Hay sold. Hay bought.
   Manure applied where? Rate per acre.
4. Liming.
   Fields needing lime as shown by vegetation. Results of acidity tests.
   Has lime been applied recently and when?
5. Commercial Fertilizers.
   Acreage of crops to be planted for 1921.
   Manure used on each?
   Amount per acre.
   Method of application.
   Brand name.
   Analysis.
   Cost?
6. Summary of methods of soil management, rotation and fertilization.
   Would the student make any changes if the management were in his hands? If so, state reasons.

Students will be assigned to this work in pairs. Map and report must be signed by each student.

Sheet 3.

Massachusetts Agricultural College.

Field Problem in Soil Management.

Directions for Sampling Soils.

1. (a) An auger 1½ inches or less in diameter may be used. (b) A spade or trowel may be used. A hole with one perpendicular side should be made and a thin slice taken from the side with any convenient instrument. Only one-fourth or one-half of this need be saved.

2. Take the samples from the plow depth. If in doubt take them from the first 7 inches of soil. Only a small amount of soil need be taken at each place.

3. (a) From fields whose soil appears to be uniform take samples according to one of the methods described above. From 6 to 10 samples should be taken at rather regular intervals, care being taken to avoid unusual situations, such as where brush has been burned, ash heaps or manure piles have stood, paths, etc. After all the individual samples are taken by one of the above methods, those for one soil type only should be thoroughly mixed in a clean pan, large sticks, stones, roots, etc., removed, and about a pint (which should represent one-third or one-fourth the mixture) removed for examination. This is a composite sample. (b) If the field contains considerable areas of soils of marked apparent differences (e. g. clay loam, sandy loam, muck) sample each type of soil as described under (a).

4. The composite sample prepared for testing should be labeled with the owner's name and the name or description of the fields from which taken. It is very important to avoid loss or confusion of labels, and it is advised that in addition to the label on the outside a label written in lead pencil on strong white paper be placed in the package of soil.

The character of the work turned in of course varies considerably in quality. Some of the students find considerable interest in the work and put in time far in excess of that required for class credit. while others put in the minimum only.

The following extracts from some of the reports should prove interesting:

(Extract 1)

Report of the Svrvey of the F——— Farm made by H. R. and G. P.

" The farm is located on the road between ——————— and ——————— and comprises about ninety acres (not including the woodland) all of which is alluvial soil.

There are some ten to fifteen acres more of woods attached to the southwest end of this farm. We were unable to obtain any measurements of these woods as Mr. F——————— was too busy to show us around and there are no land marks or other means of identifying his woods from those of the neighbors.

Moisture Control.—A good portion of the farm is well drained, but certain other parts notably pasture and meadow are in real need of some system of drainage. In the case of the pasture, Mr. F——————— did dig, some years previous, two short open ditches which emptied into the brook. These have, however, through lack of care and attention become almost completely filled so that they are now quite useless.

I could not see that it is the intention of the proprietor to install any further system of drainage, nor, in fact, to even dig out these old ditches. Apparently he has either not the time or money to place on this improvement."

(E[illegible]

"There were five acres of [illegible] and also tobacco stems which were strewn ar[illegible] [illegible] are no cover crops grown on the farm at all.

There were eight acres in hay last year but none was sold. This farm keeps, 5 work horses, 1 riding horse, 26 head of cows, [illegible] young head, [illegible] calves, 2 pigs. A few tons of hay were bought last winter.

Manure has been applied to lower field at the rate of 2½ cords per acre and on corn and tobacco land in the upper field 2½ cords per acre were also applied.

All of the pasture needs liming badly, indicated by vegetation and also six acres of land in the upper field where the soil is gravelly. Fertilizer was used on the lower field two weeks ago. There are 30 acres to be planted to 1921 crops made up of, 7 acres to soiling crops, 3 acres to corn, 10 acres to onions, 10 acres to tobacco. Muriate of potash was used as fertilizer this year. A hill-side plow was used this spring.

One suggestion I should make would be that the barns and sheds should have a better situation than they have at present. I should also drain the pasture out in the lower field. There is also a good chance to keep hens. Taken altogether I think the farm is handled on a good routine and management."

(Extract 3)

Liming.—"Fields need lime in spots. He used lime up to about three years ago but since he got a dose of potato scab he has not used it. All land shows slight acidity.

Commercial Fertilizers — He expects to plants eleven acres this year possibly more. There will be 15 tons of manure applied per acre with 600 pounds of fertilizer (Animal Brand, L. Fertilizer Company, analysis 3-8-4). On corn, potatoes, etc., the fertilizer is sowed in the hills to furrows by hand; other places a horse drawn sower is used. It costs about $57 per ton.

Mr. S——————— has got in my opinion a very nice farm. Were I running this farm I would first buy a couple of carloads of lime and use about two tons per acre, put more acreage into corn and clover. For instance he uses potato, corn and oat fertilizers while I would change this and use more clover and green manure, though there seems to be plenty of organic matter in the soil.

Nearly all his trees are headed high enough to use a tractor on where he plows and harrows the orchard once a year. I would buy a tractor and plow and harrow probably once a month. He uses a grass mulch, I would use a dust mulch."

(Extract 4)

"It seems there is no system of rotation or fertilizing. Should this land be in our hands we would recommend this land to be limed as it shows plenty of acid content by litmus tests. There should be drains put in as indicated by map diagram. There is a fine chance for an outlet as the brook or creek eventually ends in the Connecticut river. This land will eventually be used for poultry and fruit growing as this is Mr. M———————'s plans, so that is the real reason for no developments in the bringing up of soil structure."

This sort of field problem has not as yet been introduced into the introductory course for four-year students. It is intended to introduce a modification of the above problem next year.

To students, juniors and seniors of the four-year course, who elect our course in advanced soils, soil classification is stressed as shown by Sheet 4. On account of a much greater time allotted and a more extensive preparation, more exhaustive reports are expected from the advanced students than from the vocational students.

Sheet 4.

Massachusetts Agricultural College

Agronomy 75.

Directions for Field Work in Assigned Areas.

I. *General Survey*

The entire area must be surveyed and mapped (using map given). Indicate type areas on topographic map with hard pencil, letting certain numbers represent soil types. Finally the areas are to be colored using a uniform system which will be given later. A general report on the area assigned is to accompany the map. This report will include:

1. Location and boundary of area.
2. General physical features.
3. Description of soils and systems of soil management followed on them.
4. Discussion and suggestions, if any, for improvement.

The topographic map assigned must be mounted on stiff cardboard folder for field work.

Three weeks (from October 18th) will be allowed for completing this work. (Parts I and II)

II. *Detailed Survey*

In the area assigned select a farm of not less than twenty acres and, with the occupant's permission, make a detailed study of the farm from the standpoint of soil management. The final report will include:

1. A soil map of the farm on which are shown fields, brooks, buildings, etc., drawn to a scale not smaller than five hundred inches to inch. Give name of owner or occupant of the farm.
2. Detailed description of soil types on the farm and systems of soil management covering:
   a. Moisture control
   b. Methods of tillage
   c. Soil organic matter
   d. Liming
   e. Commercial fertilizers
   f. Cropping systems
3. Discussion and suggestions, if any, for improvement, with reasons.

Composite soil samples for the surface (0″–7″) and subsurface (7″–20″) of each type are to be brought to the laboratory for mechanical analyses, determination of water-retention capacity and lime requirement estimation.

Following are extracts from some of the reports on sheet 4:

(Extract 5)

1. Location and Boundary

"This area is situated in the northern part of the town of ———, Hampshire County, Mass., bordering on the Connecticut river. The southern boundary begins at the junction of the ——————— Road with the ——————— Road and extends along it to the river road. From here it extends northwest to the river then swings to the northeast meeting the ——— Road where the brook crosses it. From here the line runs southeast crossing the ——— ——— Road and gradually changing direction to southwest until it reaches the lower ——— ——— Road. (See area marked in ink on the map.)

2. General Physiographic Features.

Beginning at the river there is a narrow strip of river-laid soil which is still subject to overflow. Moving east the area is cut practically north and south by a small creek. From the creek bed the ground rises some forty feet to a ridge or series of sand knolls. A branch extends southeast from the main ridge near the southern part of the area (see map) giving the knoll a forked appearance. From this point to the eastern boundary the land lies practically level. The

altitude varies from 100 to [illegible] feet above sea level. Drainage is good except for comparatively narrow strip of marsh along the creek bottom.

3. The soil of the river flood plain is Podunk fine sandy loam. The soil is dark brown in color over brownish gray subsoil. The subsoil is sandy. Soil is well suited to grass and heavy truck crops.

Practically all the remainder of the area is Hartford fine sandy loam. The soil is brown to light brown in color underlain by yellowish sand. The soil is of glacial lake deposit and has good drainage. Topography is level except for sand ridges which may be result of wind action. The soil seems well adapted to truck crops such as tobacco, onions, and grass and corn do well.

A modification of this type is found in the sandy knolls running thru the area which correspond very closely in texture to the subsoil of this series. The formation is undoubtedly the same.

4. The Podunk soil in this area was largely in timothy with several acres of onions and a few acres of asparagus. All of these crops are doing well and seemed adapted to the soil type. The Hartford soil on the flat is growing tobacco, onions, grass, corn, potatoes and asparagus. Some stock is kept on most of the farms but most of the farmers rely largely on commercial fertilizers and turning under green crops to keep up the humus content of the soil. In most cases the farms are well balanced and the methods modern. One or two instances were noticed where the farmer was sticking to the old fashioned rotation of hay, corn and potatoes and feeding cows of medium capacity. The cream is carried to the creamery and the milk fed to young stock. One said he had been farming there forty-five years and from all appearance, he had made little change in method during that time. He would make more money if he followed the example of some of his neighbors and raised a few cash crops such as tobacco or onions."

Detailed Survey of the Farm of G. C———.

"There are two types of soil found on this farm both of the Hartford series. The fine sandy loam soil is the only soil kept in cultivation as the sandy knolls are grown up to scrub oak, pine and bushes. I think the farmer is doing right in leaving these knolls as, if they were cultivated there would be danger of their injuring the good soil by erosion and wind. This farmer practises no definite rotation but makes a practice of following grass with corn or potatoes for a year or two and then reseeding to grass and clover. The timothy is usually left about three years. Mr. C——— also has a small patch of alfalfa started but raises nothing in the line of cash crops except a few potatoes.

About twenty head of cattle are kept on the farm, the corn and hay being mostly fed out. The cream is taken to Amherst Creamery and the milk to feed the young stock. The corn showed a good yield of good grain but it would need to, on land worth upwards of $300 an acre. I think Mr. C——— would do better to raise some cash crops such as tobacco and onions and reduce the amount of stock. He already has a tobacco shed on the square of ground bought at the south of his main strip of farm land. His neighbors are making a good success of these crops and his land is practically the same."

(Extract 6)

1. Location and Boundary.

"The area surveyed was oval shaped, approximately one mile long and one-half mile wide, and situated in the town of S———, Mass. To be exact it lies due north and south and stretches from the C———homestead northward till the sharp bend in the road is met a mile further. The street railway runs thru center of the area. It is bounded on the north by the Mohawk Brook; stretches eastward as far as fourth farm house located on road to L———; on the south boundary by the Long Plain Brook and on the eastern boundary by an imaginary line one-half a mile from opposite eastern boundary at greatest width.

2 General and Physiographic Features.

The topography of the area surveyed was very much varied. Practically parallel strips of increasing altitude eastwards, ran north and south. In fact it was one continuous slope from east to west with occasionally longitudinal sandy moraines

intercepting on west side of car track and before meadows were reached. The soil is universally sandy thus giving a loose structure to the soil and providing excellent soil surface drainage thruout. Vegetation was excellent, except on moraine tops where pine and birch trees grew abundantly. Long Plain Brook which passes thru southern end of survey had overflowed often, it seems, and the old brook bed filling up with accumulated gravel and stone, had spread until rocks of considerable size and gravel and stone had been deposited in large amounts upon the lower lands causing them to be practically useless under cultivation.

3. Descriptions of Soils and Systems of Soil Management.

In general the soil was the same over the entire area surveyed, that is, a surface soil of medium sandy loam, brown in color, and a medium brown sandy sub-soil. In specific areas this varied, as in the northeastern part we found a coarse sandy top and sub-surface soil predominant, with a surplus of loose stones on surface. On the top of the sandy mounds the sub-surface and surface soils were as one. The meadows were very moist soils varying from light brown sandy soil to a silt on top; and a brown medium sand to a clay beneath. Near the brook bed the auger was hard to turn often, due to surplus stones in sub-surface soils. Eight separate farms were found on this area and their chief crops were corn, tobacco, onions, and cover crops. To these the predominating Manchester sandy loam seems especially adapted. The usual system of cropping seemed to be alternate growing of onions and tobacco, or first a cover crop, then onions, then tobacco. The land owners took exceptionally good care of fertility of their soils under cultivation and replenished with corn stalks, tobacco stalks, farm manure and commercial fertilizer, the fertility of the soil. The lower meadows were mostly in grass except where overhead irrigation was put in and here onions were grown with tremendous profit and production per acre.

4. Discussion and Improvement Suggestions.

Little waste occurs in the area under survey and in general it is a great asset to the community of S———. Each individual farmer rotated his crops every one or two years and fertilized fully to avoid depletion. One possible and surely profitable improvement would be to drain some of the lower wet meadows and grow a more profitable crop on the fertile soil besides grass. Two mucky sections on west side of car track could also be drained and better utilized. Certainly the farm buildings could be repaired and improved to advantage."

(Extract 7)

Detailed Survey of a Thirty Acre Plot on the H——— Farm.

" The H——— farm is the most prosperous and best kept up farm in the entire 'section 6'. One field, a thirty acre plot, is the best land Mr. H——— owns. He runs a large dairy, selling his cream to local stores. On the farm is a large litter of pigs and many poultry. The stable manure is well supplied with wood shavings, of which he uses a great amount for bedding.

Systems of Cropping and Fertilizing.

Mr. H————'s entire stable manure supply is used on his own farm. He uses 3 tons of lime ashes per acre on this particular plot. He secures it from an agent at $8.00 a ton. Before the war he used potash. No chemicals are used. The area grows ensilage corn and hay this year. He employs no positive or set rotation of crops, but he usually grows a two year corn and two year hay rotation, using about half the field for each crop each year. What he calls 'hay' is a mixture composed mainly of red top with either clover or alfalfa. His rotation is never definite, however. His chief fertilizer is the manure of a fifty-head herd of cows. In spite of the lime ashes, the land is quite sour.

Detailed Description of Soil Types and Soil Management.

The Gloucester and the Essex series are prevalent on this thirty acre plot, the former being far more abundant. The northern section of the field is peculiar in the arrangement of the coarse sandy loam and the medium sandy loam due to small hummocks in the area, the latter type being on the more elevated ground.

In the north-western portion, small depressions like tiny sink holes have been formed in which water rises to the surface, even in dry times. These depressions are not being drained and quite an expense would have to be utilized in their complete drainage. The land on the mounds is much more covered with small stones than that in the slightly less elevated areas. Running parallel with a telephone line, which runs diagonally from the northwest, is a rather poorly built drainage system which is now 90% clogged up. A few laterals subtend this, but with slight success. Most of the field is naturally mucky. It is some years, about 8 or 10, that 6 inch drain has been laid. The southern part of the field is mostly of the Essex series. The lower land is mucky, very fine sandy black loam with a silty subsoil. The more elevated land is nearly the same, but dryer, with a medium sandy subsoil.

Suggestions for Improvements.

The land is *awfully* sour in spite of his attempts to neutralize it with lime ashes. If money permitted, the field would be greatly benefited by a new drainage system, because the present one is not working."

(Extract 8)

Soil Survey of the R. A. S————————Farm.

" The farm is located at the extremity of P———————— Lane on the right. The house and about six acres of land, most of which is set to orchard, lies between the two roads running south drom P———————— Lane. The rest of the farm is east of the farther road in a strip 222 feet wide and extending to a brook. The general slope of this land is to the east.

There were four types of soil found on the farm. There was a small strip of Gloucester silty loam in the north-west corner of the farm. Gloucester very fine sandy loam was found on the two slopes. Suffield silty loam was found in an area at the foot of the east slope and the Suffield clay loam occupied the flat land from there to the brook.

Recommendations.

Fields 1, 2, 5, 6 and 7 are being managed well. The land which has not already been limed should be and they should be fertilized each year.

Fields 3 and 4 are in poor condition but could be made very productive for hay land if limed, drained and fertilized a little. We suggest that he run a ditch down the north side of the fields next to the woods and clean out and enlarge the old ditch on the south side. These ditches would drain into the brook. With the slight slope and the sand content in the sub-soil, we thought this would be sufficient, but if not, cross tile drains could be resorted to.

Soil Acidity and Lime Requirement. Test Made on Three Soils.

No. 1 surface (fine sandy loam) No. 3 surface (silt loam) and No. 4 surface, clayey loam. (Note, by mechanical analysis of this type I determined that this soil was a *very fine* sandy loam.)

The three first qualitative tests showed strong acidity on No. 1, medium on Nos. 3 and 4. The subsoils of each were slightly acid.

The Truog test for acidity resulted as follows:

No. 1 surface soil — very strong acidity.

Lime requirement — 4 tons per acre.

No. 1 subsoil — slight — acidity.

No. 3 surface soil — Medium + acidity; Lime requirement — 2½ tons per acre.

No. 3 subsoil — slight + acidity.

No. 4 surface soil — strong acidity; Lime requirement, 4 tons per acre.

No. 4 subsoil — very slight acidity.

Mr. S———————— had limed part of a piece of the same soil type as No. 1. When I tested the surface (limed) with the Truog method the following result was obtained:

Very slight acidity. Lime requirement. No lime may be needed but if any about ½ ton per acre.

Organic matter and Maximum Retentive Capacity.

Duplicate tests were run on the soils. The results were as follows:

Organic Matter Estimation.

	% organic matter.	
Surface of No. 1	a. 11.0% b. 9.8%	Av. 10.4%
Subsoil of No. 1	a. 4.0% b. 4.2%	Av. 4.1%
Surface of No. 3	a. 10.0% b. 9.8%	Av. 9.9%
Subsoil of No. 3	a. 5.4% b. 5.4%	Av. 5.4%
Surface of No. 4	a. 6.6% b. 6.4%	Av. 6.5%
Subsoil of No. 4	a. 3.0% b. 2.8%	Av. 2.9%

Maximum Retentive Capacity.

Soil	% Max. H_2O
Surface No. 1	38.6%
Subsoil No. 1	44.0%
Surface soil No. 3	67.5%
Subsoil No. 3	43.0%
Surface No. 4	38.5%
Subsoil No. 4	44.3%

For the Mechanical Analysis Experiment, I used the soil which I classified as clayey loam, No. 4; but the analysis of both subsoil and surface soil proved that the soil is a *very fine sandy* loam.

Mechanical Analysis of Soil No. 4. (Surface Soil) 10 grams sample of oven-dry soil used.

Separate	*Weight (grams)*		%
Fine gravel	.07		.7
Coarse sand	.30		3.0
Med. sand	.67		6.7
Fine sand	4.60		46.0
Very fine sand	1.55		15.5
Silt	2.11		21.1
Clay	.70	(by difference)	7.0
	10 grams		100.0

Or the surface soil contains
Sands.........71.9%
Silt...........21.1%
Clay...........7.0%

Subsoil

Separate	*Weight (grams)*	%
Fine gravel	.04	.4
Coarse sand	.24	2.4
Med. sand	.97	9.7
Fine sand	4.71	47.1
Very fine sand	.54	5.4
Silt	2.11	21.1
Clay	1.31	13.1

Recommendation: Same as given in report.

We feel that field work such as above reported is valuable to the student because it forces him to think in terms of soil science and soil management, because it brings him in contact with the actual farmer and his problems and because it shows the relation of soil knowledge to other phases of agriculture, particularly farm management.

THE CHARACTER OF 1919 CROP SPRING WHEAT DOCKAGE.[1]

C. H. BAILEY.[2]

During the crop year 1919–1920 the Minnesota Experiment Station, in cooperation with the Minnesota State Grain Inspection Department, conducted an investigation of dockage in spring wheat. As one phase of this investigation the dockage removed from a large number of samples was separated into its several components, and the proportion of each was determined. Two series of samples were employed: (a) four 100 sample lots of spring wheat representing inspection samples drawn by the State Grain Inspection Department at Minneapolis over a period of about eight months, and (b) samples of spring wheat collected by representatives of the Experiment Station and the State Grain Inspection Department from country elevators in the principal wheat producing sections of the State.

Dockage was separated in the manner customary to the inspection and grading of spring wheat. The total dockage was then divided into three groups or classes of material as follows: (1) coarse fraction, after separation of wild oats; (2) wild oats; and (3) fine seeds and dirt. The first fraction consisted chiefly of tame oats, barley, straw nodes, rose hips and the like. The second group was, as indicated, made up entirely of wild oats, while the character of the third group is shown in Table 2.

Table 1 gives the average percentage of each of these three fractions, the total of the three fractions, and the percentage of dockage as determined by the State Grain Inspection Department. The difference between the latter and the total found in this laboratory is not great. It is, moreover, not far different from the average dockage found in all samples of spring wheat inspected by the State Grain Inspection Department during the 1919 crop season, which

[1] Published with the approval of the Director as Paper No. 271, Journal Series, Minnesota Agricultural Experiment Station, University Farm, St. Paul, Minn. Received for publication, August 25, 1921.

[2] Associate Agricultural Biochemist, Division of Agricultural Biochemistry.

was 4.57 percent. Wild oats constituted quite uniformly about one-third of the total dockage in these samples.

TABLE 1.—*Average percentage of dockage in each of the 100 sample lots of spring wheat from the state grain inspection department.*

Dockage.	Lot 1.	Lot 2.	Lot 3.	Lot 4.	Average
Coarse dockage (except wild oats) per cent	0.72	0.47	0.27	0.28	0.43
Wild oats, percent	1.88	1.51	1.49	1.39	1.57
Fine seeds and dirt, percent	2.71	2.48	3.14	3.02	2.84
Total of the three fractions, per cent	5.31	4.46	4.90	4.69	4.84
Total dockage reported by Grain Inspection Department, percent	5.01	4.40	4.88	4.68	4.74

Barley was found to the extent of more than a trace (0.1 percent) in 45 of the 400 samples. The average quantity in these 45 samples was 1.02 percent, and calculated on the basis of the 400 samples the average in the whole was 0.11 percent, or a little more than a trace.

Tame oats were found in 29 of the 400 samples. The average in these 29 samples was 1.51 percent, and thus in the entire 400 samples the average was 0.11 percent. This is in addition to the average of 1.57 percent of wild oats.

Flax was found in 9 of the 400 samples. In four instances the quantity was fairly considerable, being 3.5, 5.0, 17.1, and 20.9 percent respectively. In the other five samples the average was 0.8 percent.

In addition to the separable impurities or dockage, the inseparable weed seeds were also determined. Corn cockle was present to the greatest extent, being found to the extent of more than a trace in 23 of the 400 samples. In these 23 samples the quantity found averaged 1.02 percent. Wild vetch, or wild peas as they are sometimes called, occurred in only 10 samples of the 400, and in these 10 samples averaged 0.52 percent. Kingheads, or the seed of giant ragweed, were found in only 6 of the 400 samples, and in these six samples averaged 0.84 percent.

The fine seed and dirt separated from each of the 100 sample lots were, after compositing, analyzed and the percentage of each of the seeds represented was determined. In addition to the weed seeds, this fraction contained appreciable quantities of small and broken wheat kernels, the average being 28.25 percent. It is impossible to completely separate such wheat either in using the sieves ordinarily employed in determining dockage or in commercially cleaning grain, especially when dealing with such shriveled, light-weight grain as constituted the bulk of the 1919 spring wheat crop. The fine seed and dirt fraction also included considerable chaff, stems, dust, etc., the average being 5.75 percent.

The principal seed components of this fraction were yellow foxtail, green foxtail, wild buckwheat, wild mustard and hare's ear mustard, these five seeds constituting 87.86 percent of the fine seeds and dirt *aftr* the wheat had been removed. The percentage of each of the components is shown in Table 2.

TABLE 2.—*Analysis of the fine seed separated from grain inspection department samples.*

Material.	Lot 1. Percent.	Lot 2. Percent.	Lot 3. Percent.	Lot 4. Percent.	Average: As found Percent.	Average: On wheat free basis Percent.
Small and cracked wheat kernels	30.00	31.00	18.50	33.50	28.25	0.00
Chaff, dust, stems, etc.	5.00	5.25	7.00	5.75	5.75	8.02
Yellow foxtail (Setaria glaucus)	18.50	21.25	24.00	21.00	21.19	29.52
Green foxtail (Setaria viridis)	36.00	28.00	34.00	23.75	30.44	42.43
Barnyard grass (Echinochloa crusgalli)	......	.50	1.25	1.25	.75	1.04
Wild mustard (Brassica arvensis)	2.50	3.50	3.75	3.75	3.37	4.70
Hare's ear mustard (Conringia orientalis)	1.50	4.00	4.00	3.00	3.12	4.35
Wild buckwheat (Polygonum convolvulus)	6.00	4.25	4.50	5.00	4.94	6.86
Ladies' thumb (Polygonum persicaria)	T	.25	.50	.50	.31	.43
Pennsylvania smartweed (Polygonum pennsylvanicum)	T	......	.75	.75	.37	.52
Pigweed (Amaranthus retroflexus)	T	.50	.50	.50	.37	.52
Lambs quarters (Chenopodium album); French weed (Theaspi arvense); Curled dock (Rumex crispus); Cow cockle (Saponaria vacarria)	0.50	1.50	1.25	1.25	1.12	1.56

T (trace) indicates less than 0.1 percent.

Recalculation of the foregoing data, shows that the 400 samples examined contained 4.03 percent of impurities of all description, including barley and tame oats. The last two items amounted, on the average, to 0.22 percent.

The 400 samples obtained from the State Grain Inspection Department represented the average of receipts from the entire spring wheat district commercially tributary to Minneapolis. In order to secure more definite information concerning dockage in Minnesota spring wheat, representatives of the two institutions were sent to

about 80 country shipping points in the principal wheat growing sections of the State, where they secured samples representative of the grain marketed at those points. For convenience in tabulating the results of tests of the samples thus secured, the territory covered was divided into three zones: (1) Minnesota River Valley, (2) Southern Red River Valley, and (3) Northern Red River Valley. Dockage in the samples from these zones was determined in the same manner as before, and Table 3 gives the average percentage of each fraction, as well as the average weight per bushel of the samples from each zone. It will be observed that the character of dockage is somewhat different in each of the three zones. Spring wheat from the Minnesota River Valley contained more wild oats and less fine seeds than that from the Red River Valley. The average quantity in all three zones was rather large, exceeding that found in the average samples from the State Grain Inspection Department. This suggests, but does not definitely establish that the foreign matter or dockage in Minnesota wheat is greater than that in wheats grown elsewhere in the spring wheat district.

TABLE 3.—*Average percentage of dockage, and weight per bushel of samples from each of the three zones in Minnesota.*

Class of Dockage.	Minnesota River Valley.	Southern Red River Valley.	Northern Red River Valley.
Coarse dockage (except wild oats), percent	0.23	0.10	1.07
Wild oats, percent	4.40	2.41	3.21
Fine seeds and dirt, percent	2.72	4.64	4.56
Total of the three fractions, percent	7.35	7.15	8.94
Weight per bushel, lbs	51.30	51.90	52.60

The fine seeds and dirt fraction from each sample was retained, those from each zone were combined and the components of each composite sample were separated. Table 4 gives the results of this mechanical analysis. As in the case of the samples from the State Grain Inspection Department, yellow foxtail, green foxtail, wild buckwheat, wild mustard, and hare's ear mustard comprised the major portion (85.94%) of the wheat-free material.

With respect to impurities which were not separated in the ordinary determination of dockage there were marked differences in the samples from the three zones. Thus, 45 of the 83 samples from the Minnesota River Valley contained wild vetch after the dockage was removed, the average content in these 45 samples being 0.74 percent, or an average of 0.40 percent in the entire lot of 83 samples. Only four of the cleaned samples contained corn cockle seed, the average in the four samples being 0.75 percent. In the samples

TABLE 4.—*Mechanical analysis of the fine seed separated from samples of wheat from the three wheat producing zones.*

Material.	Minnesota River Valley.	Northern Red River Valley.	Southern Red River Valley.	Average: As found	Average: On wheat-free basis.
	Percent.	Percent.	Percent.	Percent	Percent.
Small and cracked wheat kernels	23.5	9.5	24.5	19.17	0.00
Chaff, stems, dust, etc.	5.5	....	5.0	3.50	4.33
Yellow foxtail	39.5	23.0	39.5	34.00	42.10
Green foxtail	24.0	32.0	18.0	24.67	30.51
Barnyard grass	.8	2.0	1.0	1.27	1.57
Wild mustard	1.5	11.0	4.5	5.67	7.02
Hare's ear mustard	.5	7.3	2.0	3.27	4.05
Wild buckwheat	1.5	1.5	2.5	1.83	2.26
Ladies' thumb	1.0	1.5	0.5	1.00	1.24
Pennsylvania smartweed	.5	1.0	1.0	.83	1.03
Pigweed	.2	2.0	.3	.83	1.03
Lambs quarters	.2	4.2	.2	1.53	1.89
Mallow	....	1.5	....	.50	.62
Frenchweed	....	1.0	....	.33	.41
Evening primrose	....	1.0	....	.33	.41
Pepper-grass	.8	....	....	.27	.33

from the Northern Red River Valley about one-third contained kingheads after cleaning, with an average of 3.09 percent in these samples. The average percentage of kingheads in all the samples from this zone was 1.18 percent. Cockle, kingheads, and vetch were practically absent from the samples representing the Southern Red River Valley.

SUMMARY

Impurities are difficult of separation from shriveled spring wheat such as was represented in the crop of 1919. The fine dockage included considerable shrunken or shriveled wheat which could not be separated from the ordinary weed seeds by the usual processes of screening.

An average of 1.57 percent of wild oats was found in the 400 wheat samples obtained from the State Grain Inspection Department. The same samples contained an average of 2.84 percent of fine seeds and dirt. This consisted in large part of the seeds of green foxtail, yellow foxtail, wild mustard, hare's ear mustard, and wild buckwheat.

Wild oats constituted a larger percentage of the samples collected at 80 country points in Minnesota, averaging 3.71 percent in the 140 samples. The same weed seeds in the fine dockage predominated in these samples as in the 400 samples from the State Grain Inspection Department.

Inseparable seeds were found in varying percentages in the different sections of the State. Thus half of the samples collected in the Minnesota River Valley contained wild vetch seed, while about one-third of the samples from the Northern Red River Valley contained kingheads after cleaning. Neither kingheads nor wild vetch were found to an appreciable extent in the samples from the Southern Red River Valley.

A TREATMENT TO PRESERVE VALUABLE REPRESENTATIVE SAMPLES OF EAR CORN.[1]

C. S. DORCHESTER.[2]

One of the great difficulties encountered in Farm Crops teaching is to preserve representative specimens of grain against damage by the Angoumois grain moth and similar insect pests. It has been found very desirable to make rather extensive use of type samples or specimens for class study and exhibit purposes and anything that could be done to preserve such material would be of help in the crops teaching work. The Farm Crops Department of Iowa State College, after trying several methods, has found one which has proved very satisfactory for the preservation of samples of ear corn.

A transparent, rather glassy coating which protects against the angoumois grain moth, discourages mice, and helps to prevent the shelling of butt and tip kernels can be secured by dipping corn ears in pure white shellac. Not only does shellac protect and thereby greatly lengthen the life of a sample, but it actually improves the appearance of the corn.

From the exhibit standpoint the cost of coating with shellac is not excessive. The results of treating a number of ears with pure shellac indicate that the average cost per ear will be from 5 to 10 cents. The cost will vary considerably, the deep kernelled ears taking much more shellac than do those of the flinty, shallow kernelled type. In an effort to reduce the cost of treatment a solution of shellac and wood alcohol, half and half, was used. The coating obtained, while giving considerable protection, was found not to be heavy enough to keep out the grain moth.

In the fall of 1920 an effort was made by the college to obtain an extensive collection of corn varieties. Five ear samples of some 80

[1] Contribution from the Department of Farm Crops, Iowa State College. Received for publication November 12, 1921

[2] Assistant Professor, Farm Crops Department.

varieties representing nearly all sections of the United States were obtained. The expenditure of time and money, while not excessive, was entirely too large to be repeated in a year or two. It was thought that some protective coating or repellent might be applied to each ear. It was found that antimot, a preparation used by the United States Department of Agriculture, destroyed the luster and did not have a lasting effect. After a few preliminary tests, all of the 80 type samples were treated with a solution of shellac and wood alcohol. The alcohol was used in order that the expense of this experimental treatment might be reduced. When this exhibit was set up at the Iowa State Corn Show, a few people wondered what had been done to the corn, but the majority did not notice that it had been treated. The slight gloss imparted by the shellac enhanced the appearance of the corn.

To test the effectiveness of pure shellac, a few treated and untreated ears of Reid's Yellow Dent were stored under conditions most favorable to the Angoumois grain moth. Ear No. 1 was dipped in white shellac, Ear No. 2 in a half and half solution of shellac and wood alcohol, Ear No. 3 in antimot, and Ear No. 4 was not treated. A small cupboard containing a few old sorghum heads swarming with moths was used for the test. The corn was placed in this cupboard in the early part of the summer and left there for three months. At the end of that time an examination was made. The ear treated with pure shellac, while not entirely free from damage, was in much better condition than the other ears. Number 3 and number 4 which had the antimot treatment and no treatment, respectively, were completely riddled.

The corn ear which, so far as we know, was the first ear to be treated with shellac was treated in December 1920 and was placed on the office desk where it has been kept since that time. Untreated ears kept in the office have been so damaged by the grain moth and mice that the ears had to be removed. The shellaced ear has not been damaged in the least by the mice, but close examination in June 1921 revealed a few moth holes. These holes were marked and the ear, which in the original treatment only had been brushed with shellac, was then dipped. No further damage has been noted.

While the half and half solution used on the 80 type samples was quite satisfactory it has been deemed desirable, in view of the greater protection obtained, to use pure shellac in a second treatment of these samples.

The treatment with shellac promises to make it possible to preserve representative samples for permanent exhibit by eliminating

or greatly reducing the amount of damage from the Angoumois grain moth. Heretofore, the life of a corn sample, in spite of a more or less methodical fumigation, has been very short and the work of securing the different varieties has had to be repeated every two or three years. Samples treated with shellac and given reasonable care should keep much longer.

Besides being valuable as a method for protecting representative samples, the shellac treatment could well be used on mounted material, such as ears and ear sections, used in class and laboratory work. It is the plan of the Farm Crops Department to use shellac treated material in the making up of all new mounts.

AGRONOMIC AFFAIRS.

CHANGE IN PLACE OF PUBLICATION OF THE JOURNAL.

This JOURNAL has, ever since the beginning of its publication as a periodical, been printed and distributed by The New Era Printing Co., of Lancaster, Pa. For a number of reasons, it has now been deemed wise to transfer its publication to the J. B. Lyon Company, of Albany, N. Y. The new publishers assure the editor that they will be able to issue the JOURNAL promptly on the 15th of each month of publication, if the manuscripts are in their hands with reasonable promptness. If authors will cooperate with the editor by promptly returning corrected proofs, it seems to be possible now to assure subscribers that their numbers will in the future arrive promptly on the expected dates.

Correspondence concerning manuscripts for publication, changes in address, proofs, etc., should be addressed to the editor at the N. Y. State Agricultural Experiment Station, Geneva, N. Y.

CHANGES IN MEMBERSHIP.

The secretary has reported the following changes in the membership of the Society since his last annual report: new members, 34; resignations, 2; net gain in membership, 32. This makes the present membership of the Society, 718. In addition to this, there are 141 subscriptions to the JOURNAL by libraries, institutions, etc.

NOTES AND NEWS.

William E. Stokes has been appointed as Grass and Forage Crop Specialist at the Florida Agricultural Experiment Station.

A. E. McClymonds, formerly Extension Agronomist of the Colorado Agricultural College, has been appointed Superintendent of the substation farm at Aberdeen, Idaho.

According to a recent note in SCIENCE, Sir David Prain will soon retire from the directorship of the Royal Botanic Gardens at Kew, England. Many agronomists have been intensely interested in the researches at the Kew Gardens and will be glad to learn that the directorship is to be filled by Dr. A. W. Hill who, as assistant director since 1907, is amply qualified to continue the excellent work which is in progress.

Dr. H. H. Love, of the Department of Plant Breeding of Cornell University, during the month of January delivered lectures on the importance of the use of biometric methods in the interpretation of experimental results, at the Pennsylvania State College and at the New York Agricultural Experiment Station at Geneva.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 APRIL, 1922 No. 4

INTERTILLAGE OF CROPS AND FORMATION OF NITRATES IN SOIL.[1]

T. L. LYON[2]

Does stirring soil, as is done in the intertillage of corn, increase the formation of nitrates? Inasmuch as the land has already been plowed either in the spring or previous autumn there has been an opportunity for aeration, consequently it becomes a question whether the subsequent settling of the soil interferes with the nitrifying process. If intertillage does promote the formation of nitrates, it is presumably because of the aëration it affords. The published evidence that has been accumulated seems to indicate that stirring the soil during the growing season does not increase the formation of nitrates.

This conclusion has been arrived at by direct evidence and possibly by indirection. Evidence of the former character was furnished by Call and Sewell (1)[3] and (2) and was based on experiments in which certain field plats, kept bare of vegetation, were stirred with a corn cultivator at intervals thruout the growing season; while similar plats were scraped with a hoe to keep down weeds. These plats were sampled from time to time and determinations of nitrates were made. Such evidence should be conclusive for the soil and climatic conditions under which the experiments were performed.

What may mistakenly be considered evidence is derived from field experiments in which plats planted to Indian corn were subjected to treatments similar to those described above. No determinations of nitrates were made but the yields of corn were measured and, in the main, the two treatments produced about the same yields

[1] Contribution from Department of Agronomy, College of Agriculture, Cornell University, Ithaca, New York. Received for publication September 12, 1921

[2] Professor of Soil Technology.

[3] Reference by number is to "Literature cited", p. 108.

of grain. A considerable number of such experiments have been conducted and the earlier ones have been carefully reviewed by Cates and Cox (3), whose tabulations, when taken as a whole, indicate that cultivation is not beneficial to the corn crop except as it removes weeds, altho some of the experiments do show an increased yield of crop as the result of intertillage. Later experiments by Mosier and Gustafson (4) covering a period of eight years resulted in no larger crops of corn where cultivation was followed than where the soil was scraped. While none of these experiments are claimed by their authors or reviewers to mean that stirring the soil does not sometimes increase the formation of nitrates there is the probability that such a conclusion may be drawn, as an impression obtains in some quarters that increased formation of nitrates in a soil is always accompanied by increased crop growth. The subject is one that might well receive further investigation under conditions other than those that surrounded the experiments that have furnished the direct evidence cited above.

The reasons why further investigations are desirable may be briefly stated. The experiments by Call and Sewell were conducted in the Missouri river valley where nitrification is usually abundant owing to a large supply of nitrogen and a soil readily permeable by air because of its mechanical composition and its low moisture content. Under such conditions nitrate formation may be expected to proceed more rapidly in unstirred soil than it would in a heavier soil in a region of more copious and frequent rainfall and less active evaporation.

In any consideration of this subject it would seem to be desirable not to base conclusions on crop yields or on the nitrate content of soils on which crops are growing. It may be objected that crop yields are the ultimate consideration. But this does not explain the nitrate problem, which must be separated from the practical matter of crop yields. It should be remembered that crop production is not necessarily a measure of the quantity of available nitrogen in a soil.

EXPERIMENTS AT CORNELL AGRICULTURAL EXPERIMENT STATION.

Some experiments which were conducted at the Cornell Agricultural Experiment Station in 1911 and 1912 may add something to the available information on this subject; altho the effect of intertillage on nitrate formation was not a primary consideration in the investigation.

SOIL USED IN THE EXPERIMENTS.

The soil of the field in which the experiments were performed has been classified as Dunkirk silty clay loam. Its mechanical composition is as follows:

TABLE I.— *Mechanical composition of soil used in the experiments.*

Kind of soil.	First foot (per cent).
Fine gravel	0.40
Coarse sand	0.63
Medium sand	0.83
Fine sand	1.85
Very fine sand	12.90
Silt	60.83
Clay	22.63

The soil is a little too heavy for the best growth of corn; but following a dressing of farm manure, or a hay crop, rather good yields of corn may be obtained, sixty bushels to the acre being not uncommon.

The plats of land on which the experiments were conducted were one-hundredth acre in size, being 43.6 feet long and 10 feet wide with an intervening space of two feet. All plats were planted to corn, but a space 16 feet long and the full width of the plat was left unplanted midway between the ends. Each unplanted section received the same tillage or alternative treatment as did the planted portion of the plat. The three treatments to be discussed in this paper were (1) mulching with straw, (2) scraping off the weeds with a hoe, (3) cultivating thruout the entire growing season. The three treatments were on contiguous plats. Each treatment was repeated on four widely separated plats and the crop yields and moisture and nitrate contents of the soil here recorded are, in each case, averages of the four plats receiving the same treatment.

A diagram showing the distribution of the hills of corn on the plats, the space between the plats and the unplanted section of each plat is given below.

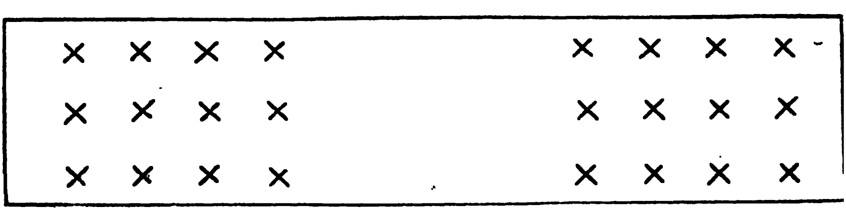


FIG. 1.— Diagram, showing planting plan of plats.

It will be noticed that there are three rows of hills on each plat. The variety of corn used was " Pride of the North " that had been grown on the same farm for many years. Five kernels were planted in each hill and later thinned to three stalks to a hill. Planting was done on May 20 in 1911 and May 22 in 1912. The straw mulch was spread on June 14 in 1911 and June 22 in 1912, at which time the corn plants were several inches high. No weeds grew on the mulched plats. The scraped plats were kept scrupuously free from vegetation and the soil was stirred as little as possible. The cultivated plats were stirred to a depth of about two to three inches with a cultivator. Cultivations were given on the following dates:

1911	1912
June 16	June 20
June 26	June 25
July 8	June 29
July 27	July 7
Aug. 21	July 20
Sept. 2	July 25
	Aug. 16

METHODS OF SAMPLING AND ANALYZING THE SOIL.

Samples of soil for moisture and nitrate determinations were taken with a one and one-half inch auger. Nine borings were made on each plat; which would be at the rate of one boring to each 48.5 square feet. Of these, six borings were made on the planted portions of the plat and three on the unplanted section. A composite was made of all the borings from the planted sections and another of the borings from the unplanted section.

Determinations of moisture were made by drying 100 grams of soil to constant weight at the temperature of boiling water. Nitrates were determined by extracting the soil with five parts of water, filtering thru a Pasteur-Chamberland filter, and using the phenol-disulphonic acid method for the remainder of the process.

In 1911, the soil was sampled to two depths, i.e., the surface eight inches and the underlying eight inches. Results indicated that it was the surface eight inches within which nitrates were largely produced and that the nitrate content of the lower depth corresponded to the upper, but in much smaller amounts. As it was expected to obtain only relative results, the second depth was omitted in 1912, but the surface borings were made to a depth of ten inches. In stating results of analysis made in 1911, the surface borings are used and the average of the first and second eight inch borings are also recorded.

NITRATES IN BARE SOIL.

The object in maintaining an unplanted section of each plat was to provide an opportunity to measure the effect of the several treatments on the nitrate and moisture content of the soil unsubjected to the influence of a crop. It will be seen in the diagrams that follow that, whereas there are marked differences in the nitrate content of the bare plats when cultivated and scraped, there are no consistent differences in the soil of the planted plats. For this reason the unplanted sections of the plats are used to measure the effect of the treatments on the formation of nitrates and on the conservation of moisture.

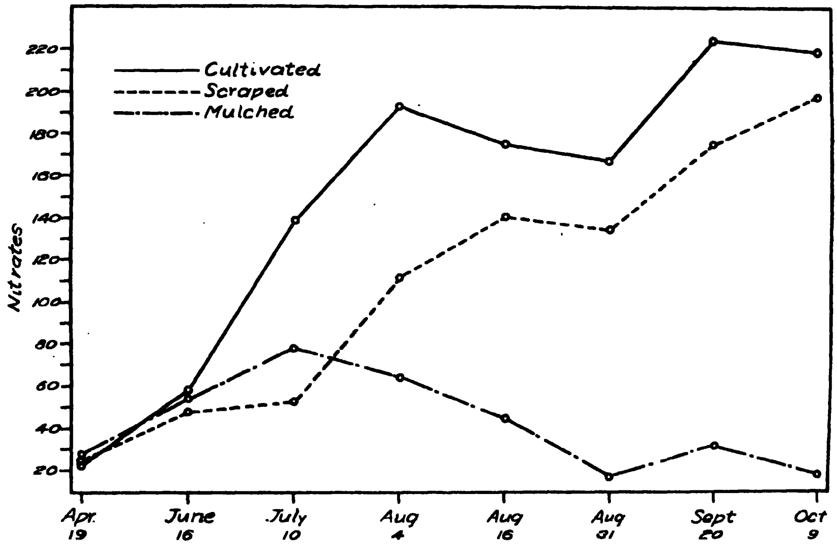


FIG. 2. Diagram showing nitrates in surface eight inches of unplanted soil in 1911.

In Figure 2[4] are graphed the nitrate determinations for each of the samples taken from the surface eight inches at various times during the summer of 1911. In Figure 3, the same data are recorded for the average of the first and second eight inches. In Figure 4, these data are shown for the surface ten inches in 1912.

The graphs referred to show in each case a marked difference in the effect of the three treatments on the nitrate content of the soil. Cultivation has perceptibly increased the formation of nitrates as compared with scraping. The nitrate content under the mulch is considerably less than under either of the other treatments. In 1911 this does not occur until after the mulch was applied; but in 1912 there was no strong recovery of the nitrifying process in the spring.

[4] The figures on which the graphs in this paper are based will be found in the appendix at the end of the paper.

MOISTURE IN SOIL.

The higher nitrate content of the cultivated plats would appear to be due to aëration of the soil rather than to any difference in the

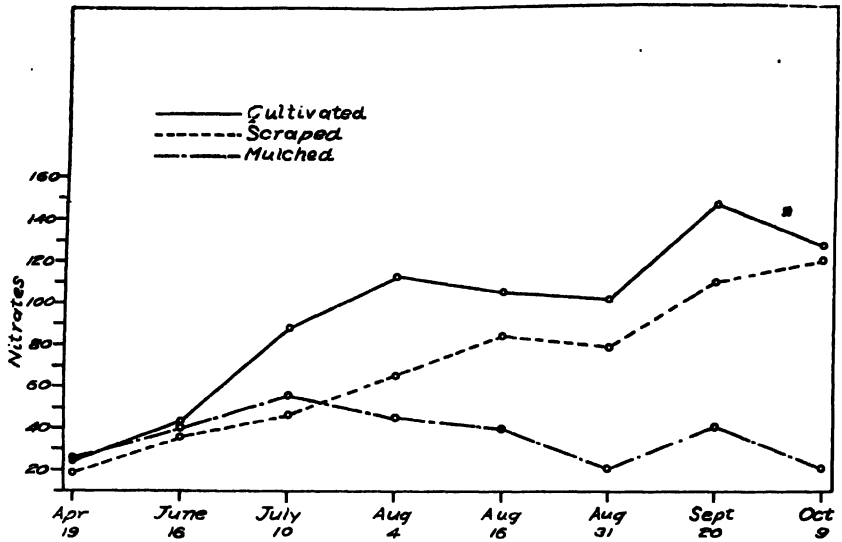


FIG. 3. Diagram showing nitrates in sixteen inches of unplanted soil in 1911.

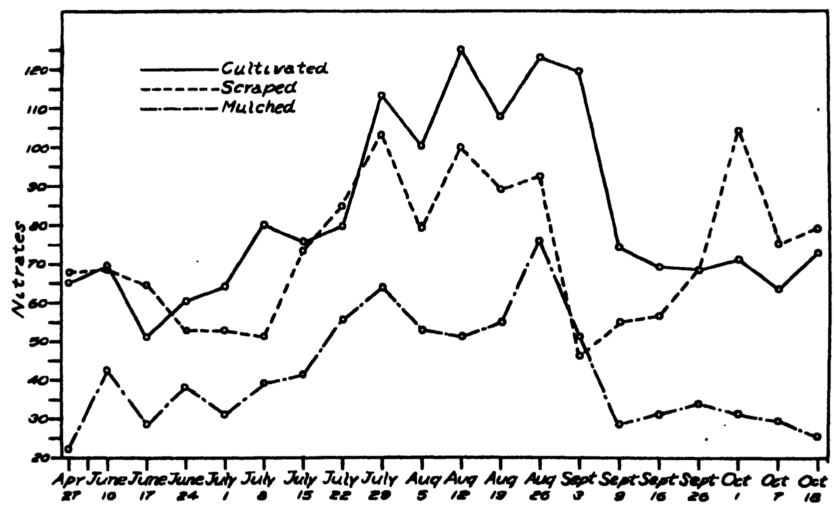


FIG. 4. Diagram showing nitrates in surface ten inches of unplanted soil in 1912.

moisture content. A graphical representation of the moisture content of the bare soil in these plats will be found in Figures 5 and 6. These show that the moisture runs higher in the mulched soil during

both years, but that there is practically no difference between the cultivated and the scraped plats during either year. The difference in nitrate content between the latter treatments can not therefore

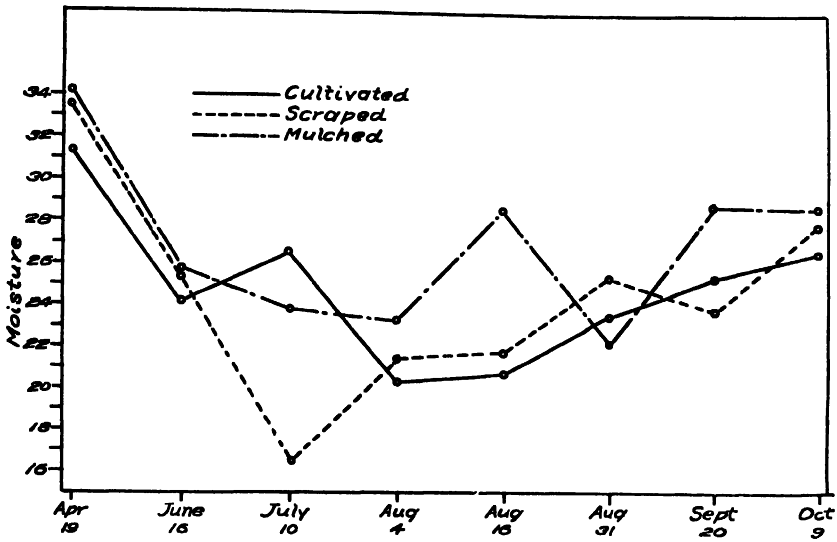


FIG. 5. Diagram showing moisture content of unplanted soil in 1911.

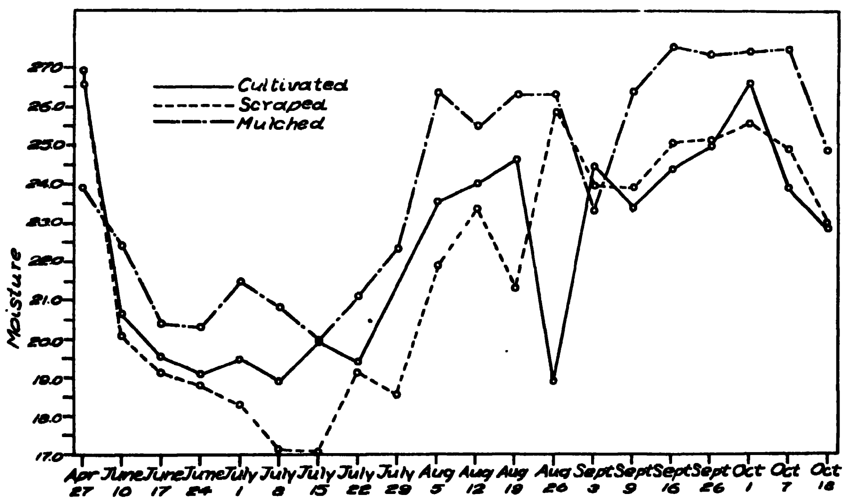


FIG. 6. Diagram showing moisture content of unplanted soil in 1912.

be attributed to the moisture content altho it is possible that the low nitrate content of the mulched plats may possibly be due in part at least to the high percentage of moisture they contained.

YIELDS OF CORN.

The corn was harvested at maturity and the weights recorded. In 1911 determinations of nitrogen in the crops were made. The results are stated in Table 1.

TABLE 1.— *Crop yields and total nitrogen.*

Plat numbers.	Soil treatment.	Yields on plats, pounds. 1911.	Yields on plats, pounds. 1912.	Nitrogen in crop. grams. 1911.
2203, 2211, 2403, 2411	Cultivated.....	159	126	541
2202, 2210, 2402, 2410	Scraped	118	116	392
2201, 2209, 2401, 2409	Mulched	145	154	494

The larger yields on the cultivated than on the scraped plats may or may not have been due to the higher nitrate content. The plats were not supplied with abundance of other available plant nutrients and there is no assurance that nitrogen was the limiting factor. In fact it was apparently not the limiting factor on the mulched plats, which, while they were always lower in nitrates than the scraped plats, gave larger yields in both years than did the latter. This is a very good illustration of the fact that the productivity of a soil is not always proportional to its facility for nitrate production.

NITRATE CONTENT OF PLANTED SOIL.

In Figure 7 and 8 are graphed the nitrate contents of the planted sections of the scraped and cultivated plats during the summers of 1911 and 1912. Unlike the bare soil the planted soil shows no consistent difference in nitrate content between the scraped and cultivated plats. Any increase in formation of nitrates resulting from cultivation has been obliterated by the growth of corn. This shows that the nitrate content of a planted soil is not a reliable indication of the rate of the nitrifying process in that soil. The absorption of nitrogen by the plants and other influences that the growing plants exert on the transformations of nitrogen make this method unreliable for distinguishing between scraping and stirring in their effect on formation of nitrates in soil.

EFFECT OF AËRATION ON THE SOIL USED IN THE EXPERIMENT.

The fact must not be lost sight of that aëration increases nitrate formation in many, if not most, soils. It is possible that there are some soils so readily permeable to air that further aëration does not promote the nitrifying process. It is likely that a compact soil is more benefited by aëration than is a loose one. The soil on which these experiments were conducted responded to aëration

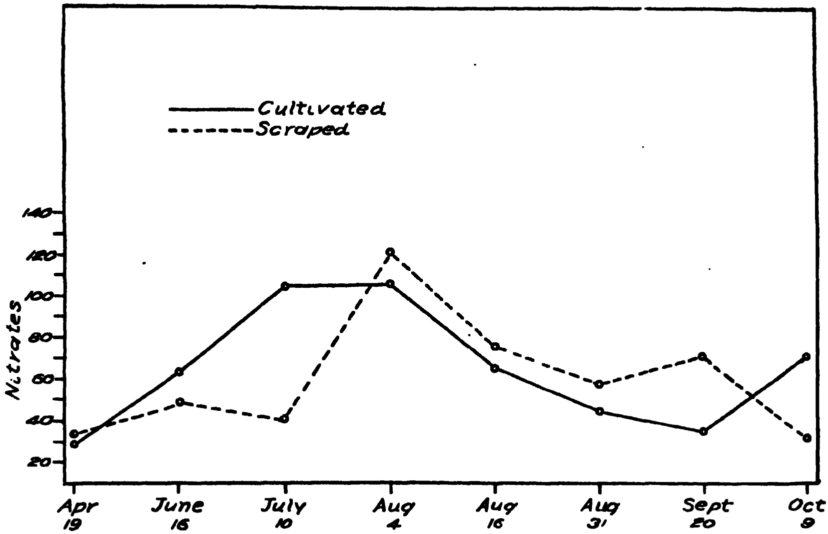


FIG. 7. Diagram showing nitrate content of cultivated and scraped, planted soils in 1911.

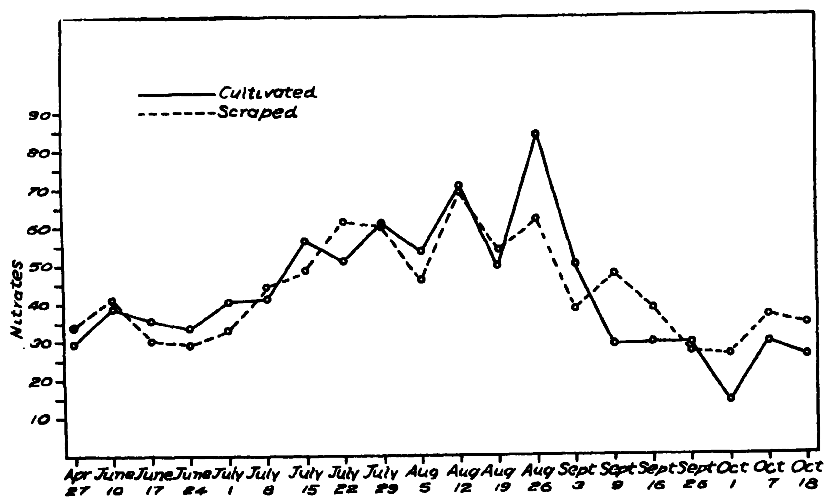


FIG. 8. Diagram showing nitrate content of cultivated and scraped, planted soils in 1912.

with increased nitrate formation. Moreover samples taken from more and less compact places in the field gave greater response from the more compact soil, as shown by the following experiments.

Samples were taken by driving into the soil an iron cylinder about eight inches in diameter and eight inches long. These samples

were transferred to a woven wire basket of about the same size, care being taken to effect the transfer without disturbing any more than was possible the cylinder of soil. The wire basket was then sealed on the sides and bottom with paraffin. Other baskets of the same size were filled with soil samples removed from the field to the same depth; but which were broken up so as to allow them to become aërated but not dried. This was done on Oct. 15. The soil stood in the greenhouse without being planted, but being maintained at a moisture content of 25 per cent of the dry weight of the soil. Nitrates were determined on November 7 and on January 5 following.

At the time that the soil samples were taken for the tests just described, estimations were made of the volume weight and porosity of the soil as it lay in the field. An iron cylinder eight inches in diameter and eight inches long was driven into the ground. The column of soil with the cylinder, was removed by digging the soil from around it and detaching the column from the lower soil by inserting a spade under the cylinder. The top and bottom of the soil column were then trimmed flush with the ends of the cylinders. The weight of the column of soil was thus obtained, and the percentage of moisture was determined in order to obtain the weight of dry soil. The interstitial space was calculated from these data.

The figures for pore space and for nitrates of both the more compact and less compact places in the field are given in table 2.

TABLE 2.—*Pore space in more and less compact soil and nitrates in the same soil aërated and unaërated.*

Soil.	Pore space per cent dry soil.	Nitrates. ppm. dry soil Nov. 7.	Jan. 5.
More compact soil, unaërated	37.5	4.2	trace
More compact soil, aërated	....	15.4	28.9
Less compact soil, unaërated	42.1	4.2	9.7
Less compact soil, aërated	....	17.6	26.0

Aëration evidently facilitated the formation of nitrates in both of these soils. The more compact soil when not aërated lost nitrates, while the less compact soil gained under the same conditions. When aërated, both soils made distinct increases in nitrate content.

YIELDS FOR FOUR YEARS ON SCRAPED AND CULTIVATED PLATS.

During two years prior to those mentioned above, tests were made of yields of corn on plats that were scraped and those that were

cultivated all season. The tests in 1907 were on a rather light sandy soil, those for 1908, 1911 and 1912, were on the soil already described. The relative yields for each year are shown in table 3.

TABLE 3.—*Relative yields of corn on cultivated and scraped plats when the former are taken as one hundred.*

Treatments.	Relative yields by years. 1907.	1908.	1911.	1912.
Cultivated	100	100	100	100
Scraped	96	89	74	92

In all cases the advantage in yield was with the cultivated plats. Whether this was due to an increased supply of nitrates or moisture or to some other cause does not appear. It illustrates, however, the result that has been obtained on a fairly heavy soil in a humid region having less evaporation than does the Mississippi valley.

SUMMARY.

Attention is called to the desirability of conducting experiments on fairly heavy soil of the North Eastern States to ascertain whether stirring with a cultivator under such conditions increases the formation of nitrates; investigations in the Middle West having indicated that stirring does not increase such action.

Experiments during two years on a silty clay loam soil at Ithaca, N. Y. to ascertain the effect of cultivating, scraping, and mulching with straw, respectively, on the nitrate content of unplanted soil and on the yields of corn are recorded.

Nitrates were highest during both years in the cultivated plats, next in the scraped, and lowest in the mulched. Determinations of moisture in these plats indicated that the higher nitrate content of the cultivated plats was not due to moisture; as that constituent was practically the same in the cultivated and scraped soil. The mulched plats had the highest moisture content.

Yields of corn were greater on the mulched than on the scraped plats; but this could not be attributed to the larger supply of nitrate nitrogen as the mulched plats also yielded more than the scraped altho the nitrates were much lower on the mulched plats. This is an illustration of the fact that the productivity of a soil is not always proportional to its facility for nitrate production.

The evidence here presented is in favor of the assumption that the nitrate content of the cultivated plats is higher than that of the scraped plats because of the aëration production by stirring with

the cultivator. Cylinders of soil taken from the field without disturbing the soil structure nitrified only slightly on standing at a moisture content and temperature favorable to the formation of nitrates, while similar soil that had been aërated gave a larger increase in nitrates. Under similar conditions a cylinder of soil from a more compact part of the field nitrified less than did one from a less compact section.

LITERATURE CITED.

1. CALL, L. E. and SEWELL, M. C. The soil mulch. *In* Jour. Am. Soc. Agron., v. 9:49–61. 1917.
2. ———, ———. The relation of weed growth to nitric nitrogen accumulation in the soil. *In* Jour. Am. Soc. Agron., v. 10:35–44. 1918.
3. CATES, J. S. and COX, H. R. The weed factor in the cultivation of corn U. S. Dept. Agr. Bur. Plant Indus., Bul. 257. 1912.
4. MOSIER, J. G. and GUSTAFSON, A. F. Soil moisture and tillage of corn. Ill. Agr. Expr. Sta., Bul. 181. 1915.

APPENDIX

TABLE 1.— *Moisture and nitrates in surface eight inches of uncropped soil during 1911.*

Dates of sampling	Moisture; per cent in dry soil			Nitrates (NO^3) ppm. in dry soil		
	Mulched.	Scraped.	Cultivated.	Mulched.	Scraped.	Cultivated.
Apr. 19....	34.1	33.6	31.4	27.2	23.3	21.8
June 16....	25.6	25.2	24.2	54.0	48.8	59.7
July 10....	23.8	16.6	26.6	78.8	52.9	138.7
Aug. 4....	23.4	21.4	20.3	64.2	112.0	192.2
Aug. 16....	28.5	21.8	20.8	46.5	141.5	174.5
Aug. 31....	22.2	25.3	23.6	13.7	135.2	168.5
Sept. 20....	28.8	23.8	25.3	31.6	176.5	224.0
Oct. 9....	28.7	27.9	26.6	18.2	198.7	209.7

TABLE 2.— *Moisture and nitrates, average in upper sixteen inches of uncropped soil during 1911.*

Dates of sampling.	Moisture; per cent in dry soil.			Nitrates (NO^3) ppm. in dry soil.		
	Mulched.	Scraped.	Cultivated.	Mulched.	Scraped.	Cultivated.
Apr. 19....	30.3	29.6	29.9	23.1	18.9	22.9
June 16....	23.5	23.6	22.3	39.9	34.6	42.8
July 10....	21.8	16.8	23.7	55.8	46.8	88.5
Aug. 4....	22.1	19.6	19.1	46.7	66.3	112.8
Aug. 16....	25.9	20.2	19.5	40.3	84.1	104.9
Aug. 31....	20.5	23.2	22.0	20.4	79.6	102.1
Sept. 20....	25.8	22.0	23.0	40.8	110.1	147.7
Oct. 9....	26.1	25.8	24.2	20.5	120.3	127.2

TABLE 3.—*Moisture and nitrates in surface ten inches of uncropped soil during, 1912.*

Dates of sampling.	Moisture; per cent in dry soil.			Nitrates (NO^3) ppm. in dry soil.		
	Mulched.	Scrapped.	Culti-vated	Mulched.	Scraped.	Culti-vated.
Apr. 27....	23.9	26.9	26.6	22.6	67.7	64.9
June 10....	22.4	20.1	20.7	43.1	67.3	69.0
June 17....	20.4	19.2	19.6	28.5	64.8	52.3
June 24....	20.3	18.8	19.2	38.5	53.8	60.4
July 1....	21.5	18.3	19.5	32.2	53.4	64.2
July 8....	20.8	17.2	18.9	39.2	52.7	80.1
July 15....	20.0	17.1	19.9	42.4	74.1	75.9
July 22....	21.2	19.2	19.4	55.9	85.2	89.9
July 29....	22.3	18.6	21.5	64.3	103.1	113.4
Aug. 5....	26.4	21.9	23.6	53.4	79.2	100.7
Aug. 12....	25.5	23.4	24.1	51.9	99.8	125.3
Aug. 19....	26.3	21.3	24.7	55.0	89.0	107.5
Aug. 26....	26.3	25.9	18.9	76.3	92.9	123.2
Sept. 3....	23.3	24.0	24.5	52.4	47.0	119.1
Sept. 9....	26.4	23.9	23.4	28.6	55.2	74.4
Sept. 16....	27.6	25.1	24.4	24.8	57.1	69.1
Sept. 26....	26.8	25.2	25.0	33.9	68.9	68.4
Oct. 1....	26.9	25.6	26.7	32.2	104.3	72.2
Oct. 7....	27.0	24.4	23.9	29.7	70.4	64.1
Oct. 18....	24.8	22.9	22.8	36.0	79.5	72.9

TABLE 4.—*Nitrates in soil planted to corn during the years 1911 and 1912.*

Dates of sampling.	1911 Nitrates (NO^3) ppm in dry soil.	
	Scraped.	Culti-vated.
Apr. 19........	32.5	28.6
June 16........	49.7	63.1
July 10........	41.5	104.7
Aug. 4........	120.7	106.7
Aug. 16........	76.2	65.5
Aug. 31........	58.5	44.7
Sept. 20........	71.5	35.0
Oct. 9........	32.1	71.0

Dates of sampling.	1912 Nitrates (NO^3) ppm. in dry soil.	
	Scraped.	Culti-vated.
Apr. 27.......	34.1	29.7
June 10.......	42.0	38.9
June 17.......	30.4	35.6
June 24.......	29.3	34.4
July 1.......	33.3	41.1
July 8.......	44.8	41.3
July 15.......	48.2	57.3
July 22.......	62.6	52.2
July 29.......	60.0	62.1
Aug. 5.......	46.5	54.1
Aug. 12.......	69.6	71.0
Aug. 19.......	54.4	50.0
Aug. 26.......	62.8	83.8
Sept. 3.......	38.8	50.3
Sept. 9.......	47.5	28.9
Sept. 16.......	38.2	29.4
Sept. 26.......	26.9	29.3
Oct. 1.......	26.2	19.1
Oct. 7.......	36.5	29.7
Oct. 18.......	34.4	26.3

A SMALL GRAIN NURSERY THRESHER.[1]

O. F. JENSEN[2] AND M. E. OLSON[3]

The thresher herein described was designed to avoid the labor of threshing by hand a large number of grain samples from yard square of similar areas used in the obtaining of plot yields from outlying fertility and crop production experiments. Three men using this machine have threshed and cleaned successfully 120 samples per hour, recording weights of both straw and grain. It is designed to be practically self cleaning so that it can be used for rod-rows, head rows, or any pure-line and plant breeding work in a small grain nursery. The thresher is not claimed to be entirely original in design; but it incorporates a number of desirable features observed in the operation of other small threshers. It can be built in its entirety by any good mechanic, the only important items to be purchased being a one-quarter horse power motor and a combined motor-forge blower with rheostat.

OPERATION.

The grain, fed through the over-shot cylinder, strikes a baffle board, and drops down into the drawer through a current of air which cleans the grain. A part of the grain and the chaff is carried onto the grain pan where a separation is effected by the air current and rapid vibration of the grain pan. All of the grain does not roll down into the drawer until the air current is shut off, which completes the threshing. The operator in feeding permits only the heads to go through the machine. Nevertheless, a few heavy pieces of straw will collect in the grain drawer. These are removed by pouring the grain through the screen, which has a slight vibratory movement.

ADJUSTMENTS.

Cylinder speed can be varied by means of different sized pulleys on the motor. The concaves can be raised from the cylinder by placing shims under the ends. The volume of the air current is controlled or shut off entirely by the rheostat. This adjustment, together with that of the angle of incline of the grain pan, makes the machine operate equally well for wheat, barley, or oats.

[1] Contribution from the Farm Crops and Soils Section, Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication November 12, 1921.

[2] Formerly assistant in crop production.

[3] Formerly superintendent field experiments.

CONSTRUCTION.

The framework is constructed of dressed lumber, two by three inches, all joints in the sides mortised and tenoned, and the two sides joined by bolts through the five cross members. The cylinder is built of maple, mounted on a piece of three-quarter inch steel shafting, and then turned on a lathe to a diameter of six inches and a length of nine and one-quarter inches. The teeth are constructed from two and one-half inch No. 16 wood screws, with the heads cut off and tops forged to a rectangular cross section. They are screwed into the cylinder in diagonal rows rather than straight across the surface of the cylinder to insure smoother running. There are eight rows of seven teeth each. The cylinder runs in saw mandrel bearings bolted on the frame and the shafting has a five inch wood pulley grooved for round belting on one end, and a similar two inch pulley on the other end.

The concaves are made of maple, two by three inches, sixteen inches long, into which are screwed teeth similar to the cylinder teeth. Both sets of concaves are mortised at the ends to set firmly in place, and are bolted to the frame by bolts and wing nuts.

The baffle board, hinged directly back of the concaves, is constructed of one-half inch lumber, as is also the board below the feed table in front of the cylinder. The feed table is constructed of matched flooring.

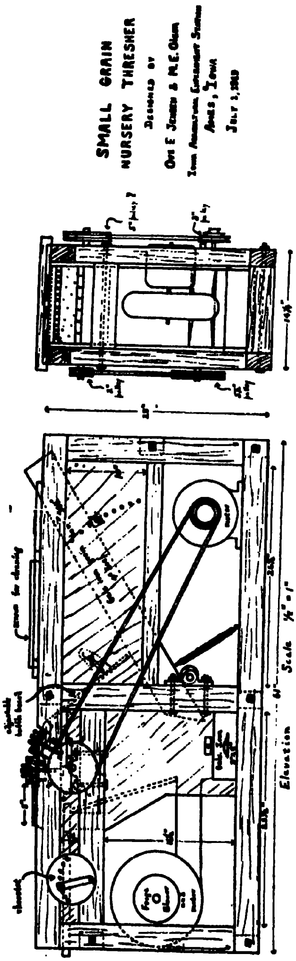
The forge blower and motor is mounted so as to direct a stream of air horizontally directly over the drawer which collects the grain, and through a sheet metal throat in which are baffle plates to insure an even distribution of air over the width of the grain pan. A rheostat mounted for convenience on the side of the machine controls the volume of air.

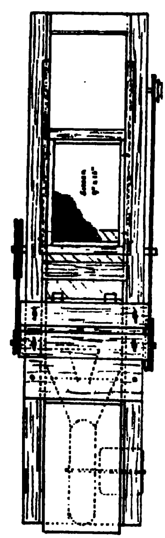
The grain pan, 36½ inches long and four inches deep, is made of sheet metal, and is supported ten inches from the upper end by an adjustable rod, on which it pivots. The lower end is held down on a cam by means of a spring. The cam is simply a two-inch circular maple pulley mounted eccentrically on three-quarter-inch shafting running in saw mandrel bearings. One end of the shafting has a five and one-half-inch wood grooved pulley, belted to the cylinder.

A frame on top of the machine holds a screen for cleaning the grain. One end of the frame is fastened by screws through holes in the top edge of the grain pan.

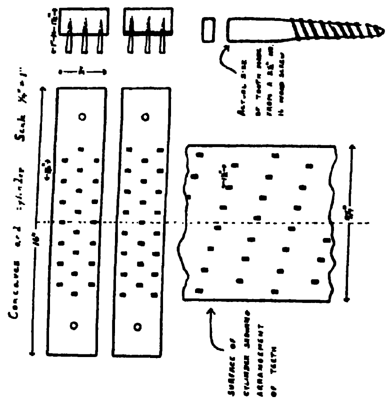
The one-quarter H. P. motor is mounted on the floor of the machine beneath the grain pan, and is connected to the cylinder with round belting. A motor having an R. P. M. of 1,750 with a

combination two, three and four-inch pulley gives cylinder speeds of approximately 580, 750, 1,000 R. P. M. and 200, 275, and 350 oscillations of the grain pan per minute.

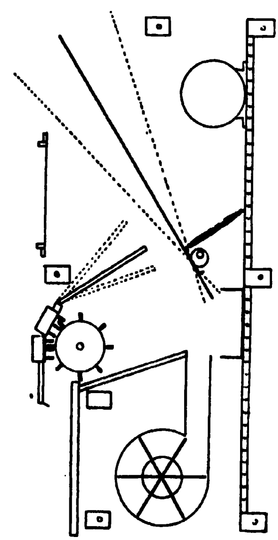




Side and end views of nursery thresher.



Concaves and cylinder, showing arrangement of cylinder teeth.



Top view and section.

THE PHYSIOLOGICAL VALUE OF SMOOTH-AWNED BARLEYS.[1]

H. K. HAYES AND A. N. WILCOX.[2]

INTRODUCTION.

The physiological importance of the awn in barley and wheat has been pointed out by various investigators. An appreciation of the facts is important to the plant breeder, for under many conditions it would seem that awned varieties may be expected to yield more than awnless.

The discomfort of handling awned varieties has led the farmer to plant awnless sorts when fairly desirable varieties of this type were available. This in turn has influenced many breeders to bend their energies toward the production of awnless varieties. Whether this practice is justifiable depends on the comparative value of awned and awnless strains.

The use of smooth-awned varieties of barley has been suggested by Harlan, of the Cereal Investigations office, Bureau of Plant Industry, and for several years cooperative breeding studies have been carried on at Minnesota and elsewhere with the hope of producing high-yielding, smooth-awned varieties of barley. The production of a new variety by crossing and subsequent selection is now based on Mendalian principles. Before introducing the new variety to the farmer, it is necessary to give it a thorough test. No smooth-awned strains are yet available for distribution but the experimental results so far obtained warrant the belief that smooth-awned varieties of high-yielding ability will eventually be produced. The evidence at hand is of two sorts: the comparative yield test of standard varieties and smooth-awned sorts, and a physiological comparison of several smooth-awned strains and certain standard varieties. Before presenting the experimental results, a brief review of earlier studies will be made.

STUDIES SHOWING THE PHYSIOLOGICAL IMPORTANCE OF THE AWN OF WHEAT AND BARLEY.

Zoebl and Mikosch (9)[3] compared the transpiration of awned spikes and of spikes with the awns removed for 2-rowed and 6-rowed

[1] Published with the approval of the Director as paper No. 289, Journal Series of the Minnesota Agricultural Experiment Station, St. Paul, Minn. Received for publication, November 25, 1921.

[2] Head of Section of Plant Breeding, Division of Agronomy and Farm Management and Assistant in Plant Breeding, respectively.

[3] Reference by number is to "Literature Cited" p. 118.

barleys and found that normal spikes gave off four to five times more water than spikes with the awns removed. Transpiration was the greatest at the time of carbohydrate formation in the seed Schmid (8) pointed out the relation between complete development of large seeds and the presence of the awn. He mentioned also the protective value of the awn.

Perlitius (7) made a careful study of the value of the awn for winter and spring wheat and for barley. Transpiration in spikes of awnless wheats was about the same as in spikes of awned wheat in which the awns had been removed. Removing the awns reduced transpiration by nearly 40 per cent in wheat and about 75 per cent in barley. The awn was shown to have an important relation on the volume and weight of the seed; the removal of the awn causing a reduction in average weight of seed of about 10 per cent.

More recently, Harlan and Anthony (4) have presented detailed results which prove very conclusively that the barley awn is an important physiological organ. They compared the daily development of kernels of clipped spikes (awns removed) with normal spikes. The found "about one week after flowering that the deposit of dry matter in the kernels of normal spikes begins to exceed that in the kernels in clipped spikes." The difference was increased progressively until maturity. They likewise found that at maturity the awns in normal spikes contained more than 30 per cent ash. When the awns were removed, a part of this ash was deposited in the rachis. This they believed to be the cause for the tendency of these spikes to break. These results may explain why hooded and awnless sorts shatter more than awned varieties.

Grantham (1,2), compared the yield of awnless and awned varieties of wheat. He found that the awned varieties averaged considerably higher in yield than the awnless and that awned varieties were less susceptible to plant diseases, such as scab. Studies carried on at the Minnesota station (6) have shown conclusively under the conditions of the experiment that the awn performed an important function. In F_3 to F_5 generation crosses of Marquis (awnless) with Preston (awned) the per cent plumpness of seed, the average length of seed per plant in millimeters, and the average yields per plant of awned and awnless plants were compared. The awned plants excelled in all three particulars.

Some of the families in F_3 and later generations were heterozygous for seed length while others were homozygous. In both the heterozygous and homozygous families the awned plants produced

an average seed length of about one millimeter greater than that of the awnless.

The use of smooth-awned varieties of barley, as has been suggested by Harlan (3), seems a logical means of overcoming the difficulties in handling awned barleys. Although smooth-awned varieties have been known for many years, Harlan has pointed out that no smooth-barley is widely grown commercially. This suggests a possible physiological limitation. The purpose of this note is to present some data which have a bearing on this question. The results are of two sorts: (1) comparative yield tests, and (2) comparative transpiration of smooth-awned and other varieties.

COMPARATIVE YIELDS TESTS.[4]

In an earlier publication (5), yield tests of smooth-awned barleys and of other standard Minnesota varieties were given. Several smooth-awned varieties were obtained which, in rod row tests, yielded as well as the standard strains of Manchuria. Two high-yielding smooth-awned strains were increased and have been tested for several years in field plots. In some years they have given high yields, but in several tests the yields have been low. This result is apparently due to the susceptibility of these new strains to *Helminthosporium sativum*. Accordingly, new crosses were made and new strains have been under rod row tests for the last two years. These new strains are resistant to *H. sativum*, as special attention was given to this character. As is shown by Table 1, they yield as well as the standard Manchuria variety.

TABLE 1.— *Comparative yields in replicated rod row tests of smooth-awned barleys and standard Manchuria. University Farm. 1920–21.*

Variety or cross.	N. S. N.	Yields in bushels per acre. 1920.	1921.	Average.
Manchuria	Minn. 184	48.4	31.2	39.8
Smooth Awn x Manchuria	II–20–7	41.7	31.1	36.4
Smooth Awn x Manchuria	II–20–8	45.8	33.2	39.5
Smooth Awn x Luth	II–20–9	55.5	33.2	44.4
Smooth Awn x Luth	II–20–10	58.2	32.4	45.3
Arequipa x Smooth Awn	II–20–14	44.5	35.4	40.0

COMPARATIVE TRANSPIRATION OF HEADS OF SMOOTH-AWNED AND OTHER BARLEYS.

Culms of the varieties to be used were collected in the field by cutting them as near the base as possible. They were placed in a

[4] Barley breeding is in cooperation with the Office of Cereal Investigations. The original crosses were made and the F_1 generations grown by Dr. Harlan of this office. Subsequent breeding studies have been carried on at the Minnesota station.

pail of boiled water and were then cut beneath the surface of the water at a point separated from the first cut by at least two nodes. Care was taken to use heads in which the seeds were at about the same stage (late milk) of development. After bringing this material to the laboratory, the stems were again cut under water, leaving about four inches of stem below each head. These stems were then inserted into 4-ounce, wide-mouth bottles. The bottles were previously prepared by filling with boiled water and by stretching across the mouth of each and fastening with a rubber band, a three-inch square piece of dental rubber dam which was punched with eleven fine holes, ten of which were for the barley stems and the other to carry a fine glass tube which was to serve for admitting air to take the place of the transpired water. Each of the bottles in turn was then immersed in water in the pail which contained the barley stems, so that they could be inserted through the holes in the rubber without admitting air to the stems. After the stems were inserted the rubber dam was loosened so that it contracted about the stems, holding them tightly and preventing evaporation of water from the bottle. The rubber was then held in place by a rubber band around the neck of the bottle.

TABLE 2.— *Comparative transpiration of smooth-awned, rough-awned, rough-awned with the awns removed, hooded, and awnless barleys.*

Variety.	Type.	Transpiration by 10 heads (single determination) in grams.	Period of transpiration hours.	Average length of awn cm.
Manchuria (check)	6-rowed, awns rough	58.9	57.35	9.5
Manchuria (check) ½ awns clipped	6-rowed, awns rough	44.8	57.45	10.5
Manchuria (check) all awns clipped	....	24.5	58.15	......
Manchuria I-15-2	6-rowed, awns rough	76.1	58.40	12.0
Minsturdi	6-rowed, awns rough	58.7	58.35	9.5
Arequipa	6-rowed, awns rough	48.0	59.25	14.0
Trebi	6-rowed, awns rough	58.4	58.55	13.5
Meloy	6-rowed, hooded	28.4	59.20	......
Arlington awnless	Intermedium, awnless	19.3	59.20	......
II-20-9 Smooth Awn x Luth	6-rowed, awns smooth	55.6	57.45	10.0
II-20-8 Smooth Awn x Manchuria	6-rowed awns smooth	65.2	59.00	9.5
II-20-14 Arequipa x Smooth Awn	6-rowed, awns smooth	63.8	59.00	12.0
II-20-10 Smooth Awn x Luth	6-rowed, awns smooth	60.6	59.05	10.0
II-20-7 Smooth Awn x Manchuria	6-rowed, awns smooth	55.1	58.45	9.6

The bottles with heads inserted were placed near a window in the laboratory, the amount of water transpired being determined by weighing the bottles from time to time. The period of transpiration is not exactly the same for all varieties as they were moved about from time to time on the table and then weighed at random. The slight variations are not, however, of great importance.

The transpiration results (see Table 2) are of like nature to those previously reported by other investigators.

Meloy hooded, Arlington, awnless, and clipped heads of Manchuria gave off a total of 28.4, 19.3 and 24.5 grams of water respectively, while normal Manchuria gave off 58.9 grams (see Table 2). The five smooth-awned strains gave off from 55.1 to 65.2 grams and averaged 60.1 grams.

TABLE 3.— *Comparative transpiration of smooth-awned barleys, of rough-awned, and of rough-awned with the awns removed.*

Variety.	Transpiration by 10 heads, in grams. Test A.	Test B.	Test C.	Average.	Period of transpiration.	Average length of awns.
Manchuria (check)	83.2	74.2	81.2	79.5	47.05	9.5
Manchuria (check) clipped	28.7	25.3	25.3	26.4	46.45	....
II-20-8 Smooth Awn x Manchuria	67.1	72.8	69.7	69.9	46.45	8.5
II-20-9 Smooth Awn x Luth	62.7	59.0	74.0	65.2	46.55	10.0
II-20-10 Smooth Awn x Luth	82.1	80.0	79.9	80.7	46.55	9.0

A second experiment was made in which Manchuria and three smooth-awned strains were used, each experiment being run in triplicate. Two of the smooth-awned strains gave off somewhat less water than Manchuria, while one strain gave off a slight percentage more. (See Table 3.)

SUMMARY.

The awn of barley and wheat is an important physiological organ. Under various conditions it has been shown that awned varieties give higher yields than awnless. These results should be considered by plant breeders and farmers before deciding to grow only awnless varieties.

The use of smooth-awned strains of barley will, in a large measure, overcome the unpleasant features of handling rough-awned varieties. Comparative yield tests and comparative studies in transpiration of heads of smooth- and rough-awned varieties indicate that smooth-awned barleys have no physiological limitations when compared with standard rough-awned varieties.

LITERATURE CITED.

1. GRANTHAM, A. E. Wheat investigations — varieties. Del. Agr. Exp. Sta. Bul. 121. 1918.
2. ——— Bearded vs. smooth wheats for Delaware. Del. Agr. Exp. Sta. Ext. Bul. 6. 1919.
3. HARLAN, H. V. Smooth-awned barleys. *In* Jour. Amer. Soc. Agron. v. 12: 205–208. 1920.
4. ——— and ANTHONY, STEPHEN. Development of barley kernels in normal and clipped spikes and the limitations of awnless and hooded varieties. *In* Jour. Agr. Res. v. 19:431–472. 1920.
5. ———and HAYES, H. K. Breeding investigations. *In* Minn. Agr. Exp. Sta. Bul. 182: 45–56. 1919.
6. HAYES, H. K. Inheritance of kernel and spike characters in crosses between varieties of *Triticum vulgare*. In Press.
7. PERLITIUS, LUDVIG. Der einfluss der begrannrung auf die wasserverdunstung der ähren und die kornqualität. Merseberg, Inaug-Diss. Breslau. 77 pp. 1903.
8. SCHMID, B. Bau und functionen der grannen unsere getreidearten. Bot. Centralblatt, v. 78: 328–330. 1898.
9. ZOEBL, A. and MIKOSCH, C. Die function der grannen der gerstenähre. Sitzber, K. Akad. Wiss. (Vienna) Math. Naturw. Cl., Band 101, Abt. 1, pp. 1033–1060. 1892.

THE EFFECT OF NITRATES APPLIED AT DIFFERENT STAGES OF GROWTH ON THE YIELD, COMPOSITION, AND QUALITY OF WHEAT.[1]

JEHIEL DAVIDSON.[2]

INTRODUCTION.

An experiment on the effect of sodium nitrate, applied at different stages of growth, on the yield, composition, and quality of wheat, previously conducted by this laboratory (1)[3], showed that when applied during the early part of the vegetative period sodium nitrate increased the yield of the crop, when applied at the time of heading it improved the quality of the grain, and when applied at the beginning of the milk stage it had no effect on the yield or quality of the crop.

In the experiment reported in this paper, the vegetative stage was subdivided into three periods. Each of three corresponding sets of plots received an application of nitrates at one of these periods.

[1] Contribution from the Plant Chemical Laboratory, Bureau of Chemistry, U. S. Department of Agriculture, Washington, D. C. Received for publication, December 2, 1921.

[2] Soil Chemist.

[3] Reference by number is to "Literature cited," p. 122.

The object of the experiment was to determine whether the effectiveness of the nitrates in increasing the yield of the crop disappears sharply when applied at a certain critical stage of development or disappears gradually when applied as the season advances toward the completion of the vegetative stage.

The experiment was carried out in the year 1919, at College Park, Maryland.[4]

PLAN OF THE EXPERIMENT.

For certain reasons, which need not be discussed here, it was considered desirable to compare the effects of sodium nitrate with those of calcium nitrate. To determine the effects of the bases (sodium and calcium), additional plots were treated with sodium nitrate and calcium sulphate and calcium nitrate and sodium sulphate. For the sake of further control, plots which received calcium sulphate and sodium sulphate alone were added. The experiment was carried out in duplicate. Samples taken in the remainder of the field by the small plot harvester (2) served as controls. Owing to the general lack of uniformity in the field, however, it is best to regard the twenty-four plots which received nitrates as separate sets of three plots corresponding to the three subdivisions and compare the plots with one another in every set. The plots, which were one square rod, with two-foot alleys between them, were laid out after the crop was up.

DIAGRAM 1.—*Description of plot treatments and the order in which they were laid out.*

No. plot	Fertilizer	Period	No. plot	Fertilizer	Period	No. plot	Fertilizer	Period
1	Sodium nitrate...	1	13	Calcium nitrate + sodium sulphate	1	25	Calcium sulphate.	1
2	"	2	14	"	2	26	"	2
3	"	3	15	"	3	27	"	3
4	Calcium nitrate..	1	16	Sodium nitrate + calcium sulphate	1	28	Sodium sulphate..	1
5	"	2	17	"	2	29	"	2
6	"	3	18	"	3	30	"	3
7	Sodium nitrate + calcium sulphate	1	19	Calcium nitrate..	1	31	Calcium sulphate.	1
8	"	2	20	"	2	32	"	2
9	"	3	21	"	3	33	"	3
10	Calcium nitrate + sodium sulphate	1	22	Sodium nitrate...	1	34	Sodium sulphate.	1
11	"	2	23	"	2	35	"	3
12	"	3	24	"	3	36	"	2

The plots were laid out in the order shown in Diagram 1. The soil was a Susquehanna loam. The seed was a China red soft winter

[4] Occasion is here taken to acknowledge the assistance of Director Paterson and Professor J. E. Metzger of the Maryland Experiment Station.

wheat. The date of application of the fertilizers for the plots of the first period was April 11, for those of the second period, April 24, and for those of the third period, May 14. The chemicals were applied at the rate of 320 pounds an acre — 2 pounds to each plot.

YIELD OF CROPS.

Photographs showing the difference in the stands on the plots receiving three different applications were taken when the wheat was fully headed. The weights of the entire crops were taken immediately after harvesting and again before threshing. While there was an appreciable loss of weight between the two weighings, the same general tendency was apparent in each case. The figures in Table I are the results of the last weighings. The weights of the grain were taken immediately after threshing.

TABLE I.— *Yields and percentage of grain.*

Treatment.	Period	Weight of crop.			Weight of grain.			Percentage of grain.		
		1st series	2nd series.	Aver-age.	1st series.	2nd series.	Aver-age.	1st series.	2nd series.	Aver-age.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Per-cent.*	*Per-cent.*	*Per-cent.*
Sodium nitrate.......	1	37	39	38.0	10.6	9.5	10.05	28.7	24.3	26.5
	2	34	25	29.5	9.5	6.4	7.95	27.9	25.5	26.7
	3	24	16	20.0	8.2	4.7	6.45	34.1	28.5	31.3
Calcium nitrate......	1	39	37	38.0	11.6	9.5	10.55	29.8	25.7	27.7
	2	36	30	33.0	10.2	9.0	9.60	28.5	30.0	29.2
	3	32	25	28.5	9.1	7.5	8.30	28.3	30.0	29.1
Sodium nitrate and calcium sulphate...	1	40	30	35.0	9.7	8.4	9.05	24.2	28.1	26.1
	2	30	24	27.0	8.0	6.4	7.20	26.7	26.5	26.6
	3	21	20	20.1	6.9	6.2	6.55	32.7	31.3	32.0
Calcium nitrate and sodium sulphate.	1	40	40	40.0	10.1	10.6	10.35	26.5	26.4	26.4
	2	30	31	30.5	7.2	8.1	7.65	24.0	26.6	25.3
	3	16	24	20.0	5.8	7.2	6.50	36.3	30.2	33.2
Calcium sulphate.....	1	23	13	18.0	7.8	4.3	6.05	33.9	33.3	33.6
	2	21	15	18.0	6.8	5.2	6.0	32.1	34.4	33.2
	3	30	14	22.0	9.6	4.6	7.1	32.1	32.8	32.4
Sodium sulphate.....	1	18	13	15.5	6.0	4.7	5.35	34.2	34.2	34.2
	2	13	12	12.5	4.7	4.2	4.45	37.5	37.5	37.5
	3	17	8	12.5	5.5	2.6	4.05	32.4	34.2	33.3
Control.............	....	17.4	18.6	18.0						

Both photographs and weights show strikingly that the effectiveness of nitrates in increasing yields gradually decreases as the time of application approaches the season of heading of the grain. The plots which received their nitrate application at the first period gave the highest yields; the plots which received it at the second and third periods followed in regularly diminishing order. This is true of the grain as well as of the entire crop. Altogether eight sets

of three plots each received nitrates, and in no case was there a single exception from the general rule.

In the majority of cases, the percentage of grain to crop is greater on the plots which received the nitrate application at the third period.

It is impossible to draw any conclusion as to the effect of the sulphates on yield. The yield variations from the plots which received sulphates alone do not consistently follow any principle. They seem to be caused largely by natural variations in the field.

QUALITY AND COMPOSITION OF GRAIN.

The wheat, being of a soft winter variety, did not exhibit the characteristics of typical "yellow berry" or "flinty" grain. Its general variation in color from yellow to brown, however, conformed distinctly to the order of the time of application of the nitrates. The grain from the plots which received nitrates at the third period especially was decidedly more brown than that from the plots which received the nitrates at the other two periods.

TABLE 2.— *Percentage of protein (nitrogen × 5.7) in grain.*

Treatment.	Period.	Protein. 1st series. *Percent.*	2d series. *Percent.*	Average. *Percent.*
Sodium nitrate....................	1	13.13	12.53	12.83
	2	13.92	12.97	13.44
	3	15.59	14.47	15.03
Calcium nitrate..................	1	12.47	12.37	12.42
	2	13.07	13.10	13.08
	3	14.44	14.68	14.56
Sodium nitrate and calcium sulphate.	1	13.04	12.22	12.63
	2	13.54	12.82	13.23
	3	15.00	14.12	14.56
Calcium nitrate and sodium sulphate.	1	12.75	12.33	12.64
	2	12.93	13.95	13.44
	3	14.11	14.91	14.51
Calcium sulphate..................	1	11.32	11.27	11.29
	2	11.38	11.17	11.27
	3	11.90	10.82	11.56
Sodium sulphate..................	1	11.14	11.25	11.19
	2	11.18	11.12	11.15
	3	11.26	10.92	11.09
Control	...	11.90	.....	.....

Without an exception the protein content (N x 5.7) increased regularly as the crops at the time of application advanced toward heading (see Table 2). While the grain on the plots which received their application at the second period showed consistently higher nitrogen contents than that on the plots which received it at the first, the differences are not considerable. The grain on the plots which received their application at the third period, which was

close to the time of heading, and which gave the lowest yields, showed appreciably increased nitrogen contents. It will be noted that the protein content of the grain on the plots which received their application at the first period was higher than that of the grain from the control and sulphate plots. The [illegible] lots had a lower protein content than that on the [illegible] ortunately the analysis of only one control sample is available. The figures from the sulphate plots, taken by themselves, however, seem to indicate a depressed nitrogen content.

The ash and phosphoric acid contents of the grain were also determined. As the results exhibit no consistent tendencies, they are not given here.

SUMMARY.

The period between the resumption of growth of wheat in the spring and the time of heading was divided into three sub-periods. Each of three corresponding sets of plots received nitrates at one of these sub-periods. The results thus obtained show that:

1. The effectiveness of nitrates in increasing yields decreases consistently as the time of their application approaches the stage of heading.

2. The effectiveness of nitrates in increasing the protein content (N x 5.7) of the grain increases as their effectiveness in increasing the yield decreases.

LITERATURE CITED.

1. Davidson J., and La Clerc, J. A. The effect of sodium nitrate applied at different stages of growth on the yield, composition, and quality of wheat. *In* Jour. Am. Soc. Agron. v. 9, 145–154 (1917); and v. 10, 193–198 (1918).
2. McCall, A. G. A new method for harvesting small grain and grass plots. *In* Jour. Am. Soc. Agron. v. 9, 138–140 (1917).

A PLEA FOR EXPERIMENTAL WORK IN CROPS TEACHING.[1]

S. B. HASKELL.[2]

My interest in this subject dates back [illegible] instructor in an agricultural [illegible] place crop teaching on a sound pedagogical basis. In time, I passed on to my successor this problem still unsolved. Later on, as opportunity came, I made random observations on crop teaching as done at some twenty-six of the agricultural colleges. I talked with instructors, I talked with the students, I studied catalogs. I compared crop courses with soil fertility courses, likewise with courses in what is called fundamental science. Opportunity has never come to make such a study of the subject as is warranted by its importance. My conclusions, however, frankly based upon the abovementioned more or less random observations, are as follows:

1. Crop credits are generally recognized by students as being cheap credits. The amount of time required outside of class is relatively low; the intensity of attention in the class is seldom high.

2. The mental training value of crop courses is open to question. They certainly do not compare favorably in mental training values with courses in science.

3. Observation training values are fair, although oftentimes not correlated with mental training.

4. The work required, at those places where the credit hour in crops has a real significance, is largely routine in its nature.

5. Crop courses as taught are oftentimes not founded on science. Men without the scientific training advertised as prerequisite have no difficulty in keeping pace with students who have taken the so-called fundamental science prerequisites.

6. In some rare cases, where a real attempt is made to found the work on science, there is duplication of effort inside of the institution, in that the science itself rather than its use as a tool is taught, under the guise of technical subject matter.

While the foregoing are merely statements of opinion, they are susceptible to proof or disproof. To determine the facts on the first three points, we must go directly to students who have taken or are taking courses in crops. The testimony of their instructors

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Director, Agricultural Experiment Station, Amherst, Mass.

is relatively of little value. Instructors theorize on what ought to be the results of the methods of teaching followed. Students base their statements on the actual experiences which they are undergoing. Not until crop instructors as a whole study the reaction of students to crop teaching as it is done can we expect the work to be on a sounder basis. The validity of the fourth charge, however, can in a measure be determined from a study of laboratory, lecture, or other class outlines. The use made of prerequisite science courses can be determined by a study of records of students in crops who have or have not taken these science courses, also of the course as outlined for men of different degrees of previous training. To obtain the facts as to the last assertion, we must get both the statements of instructors and the statements of the students. The final complex will establish the justice, or otherwise, of the charge made.

For the sake of argument, let us assume that my assertions represent facts. The state of affairs as pictured is not recent. I remember that at the meeting of the American Society of Agronomy held at East Lansing in 1912, Professor W. M. Jardine, now President of the Kansas Agricultural College, made the statement that "Our crop courses are cheap," and supported it in his usual vigorous manner. To give emphasis he reiterated the charge again and again, and certainly succeeded in getting marked attention. This, however, was nearly ten years ago; hence the question "Have our crop teachers made progress during the last decade" is entirely legitimate. If not, is the fault due to the limitations, inherent limitations it may be, of the subject matter. Or, is the basic trouble in our own limitations as crops teachers.

That there has been absolute progress in the last decade must be admitted by any impartial student of agricultural teaching. Remember, however, that progress is of two kinds, relative and absolute; and some of us will deny the relative progress in crop teaching methods. As an illustration of this, the past decade has seen instructional work in soils and soil fertility elevated from the kindergarten class to a rank second to no subject taught in agricultural colleges. Ten years ago, students were required to spend endless and expensive hours in the soil laboratory. They weighed and reweighed brass tubes, and powdered mineral matter which they fondly hoped represented soils; and estimated moisture on the surface and in the interior of all sorts of things. Yet when the attempt was made to bring together the scattered knowledge thus developed, and figuratively speaking to "cash in" on the laboratory technique so developed, the work left much to be desired. Today,

however, the subject of soils and soil fertility is recognized as being on the plane of interpretative science. Its function is to draw from all science such facts as apply to the problems of fertility and soil management. Its success as a college course is based largely on the fact that the mental training value of work so given was early apparent. The men attracted to soil courses were of the highest degree of ability. The real question at issue, therefore, is whether our crop courses have relatively lost or gained when compared with those other courses which compete with the study of crops for the time and attention of the student.

THE FUNCTION OF THE COLLEGE COURSE IN CROPS.

Crop production itself ranks as an art. By no stretch of the imagination can it be called a science. The term "scientific crop production" is an anomaly. True it is, however, that certain practices in crop production may have a sound foundation in science, or the reverse may be the case. If, however, the college subject of crops is taught as an art, then we are elevating to college rank something that really belongs in the vocational school. Such schools aim primarily to teach how to accomplish or to do certain things. The college course in these subjects aims at — come to think of it, just what is the aim of a college course in crops? Has it ever been defined in any effective sort of way? Has the line of demarcation between the vocational school course in crops and the college course in crops ever been established?

I must turn aside from the general subject of crop courses for the minute to make a statement of three platitudes, on which I shall base as a conclusion what I conceive to be a sound definition of the objective of the college course in crops. These platitudes are:

1. The function of a college is to teach men to think clearly. In this the college differs from a school, the function of which is to teach how to do.

2. The function of a vocational college, then, is to teach men how to think clearly, rapidly, soundly and constructively in terms of a vocation.

3. The function of an agricultural college, therefore, is to teach men to think constructively, productively and efficiently in terms of agriculture as a vocation.

Finally, and as a conclusion, the function of the college course in crops is to teach men how to think, constructively and productively, in terms of problems of crop production. As a corollary, it must teach students to see what there is to be seen, and to reason accurately and rapidly, from these observations, to sound conclusions.

Now if we accept these statements as sound we have at once a basis on which we may evaluate methods of crop teaching. We may judge of their value or their lack of value by the extent to which they promise the economical attainment of the objectives just stated.

WHY NOT EXPERIMENTAL WORK ON TEACHING METHODS?

At meetings of the American Society of Agronomy, at our local meetings of the New England section of this society, in conferences with crop and soil teachers all over the northeastern quarter of the country, I have heard much of curricula — of the place occupied by crop courses in these curricula — of relationship of crop courses to what are called prerequisite science courses — of the relationship of the study of crops to the study of soils, of farm management, and of various other similar subjects. I have been impressed with the utter futility of much of this discussion. It deals with the mechanics of arrangement, but does nothing, absolutely nothing, toward placing the teaching of crops on a sound pedagogical basis. In fact, it is useless to discuss the place of crop courses in the curriculum unless the major objective of these courses be clearly defined. The failure of such courses, if grouped in one place, will be no less serious than if grouped in another. Furthermore, unless the students are inspired or even compelled to use as tools the subjects required as prerequisites, then these same prerequisites are practically non-essentials. They may indeed be included for their mental training values, but if so this should be so admitted frankly and freely. Opinions may differ as to the importance of these prerequisite sciences in the study of crops. There can be no difference of opinion as to the necessity of clear realization of just why such courses are included in the curriculum. Now, contrasting strongly with eternal discussion on the mechanics of arrangement, we seldom hear of crop teaching in its human relationships, nor yet of the relative value of different methods of attaining the prime objectives — which, let me repeat, should be increased ability on the part of the student to really think in terms of his subject matter. This brings me to a suggestion which I make with some hesitation — why should not the American Society of Agronomy do experimental work in determining the final values of different methods of crop teaching? There is real need for this service. The time our students spend in crop courses is expensive. As crop instructors we cannot afford to have our courses of any less value to the men taking them than are other courses, regardless of what they may be, which are offered in an agricultural college.

AN OPPORTUNITY FOR SERVICE.

I look upon this suggestion as a presentation to the American Society of Agronomy of an opportunity for real service. In order to render possible easy criticism of the suggestion, I will present it in the form of three steps which I believe should be taken. These are:

1. Determine the facts as regards crop teaching as actually being done. I have presented nothing more than an opinion based upon more or less consistent, but nevertheless random, observation. I may have overdrawn certain things in the picture which I attempted to present. Therefore let the American Society of Agronomy determine the facts and publish the same without fear of favor. This is the first big service which may be rendered by the Society.

2. Make a critical study of teaching methods now in use. Define objectives. Find how different instructors aim to compass the same objectives. Catalog these methods.

3. Outline definite experiments in methods of teaching. Select a number of methods designed to attain the same objective, test them out in different institutions, in different classes in the same institution, on different individuals in the same classes. Develop machinery for measuring, no matter how inefficiently, the reaction of the student. Evaluate our crop teaching methods in terms of the human element rather than in terms of the subject matter itself.

Of necessity, before we can take action or organize work on recommendation No. 3, recommendations Nos 1 and 2 must be acted upon. In case it is possible, however, to organize the work outlined in No. 3, I must emphasize that the basis of final judgment must be the reaction of the student, the interest aroused in him, the type of men attracted to crop courses, and the ability of the student, once exposed to our crop teaching, to apply scientific thought to subject matter problems, and finally, his ability to see clearly and reason accurately from that which he has seen.

Does this represent an easy program? No. A necessary program? I believe the answer must be in the affirmative. Yet I believe that the work, onerous though it may be, will be worth while for the sake of the good standing of one of the most important courses in our agricultural colleges. Furthermore, we should always remember that the most serious waste in college is time waste; and that the least excusable of these time wastes is that which a student may be forced to waste in class or laboratory. Therefore the fundamental necessity of this study lies in the fact that it is incumbent upon us to guarantee the essential worthwhileness of the time spent by students, in crop studies.

REPORT OF THE COMMITTEE ON LECTURES FOR A STANDARD INTRODUCTORY COURSE IN FIELD CROPS[1]

In offering an outline for the lectures of a standard *introductory* course in Field Crops, the Committee feels that some discussion of its choice and organization of subject matter is desirable, by way of explanation and emphasis.

Is a Standard Introductory Course Desirable?— The Committee defines this course as a selection and organization of the introductory subject matter of Field Crops, which can be taught with considerable uniformity among the leading agricultural colleges of the country. The Committee believes a standard course is not only desirable but necessary, if Field Crops is to grow in power and dignity as a distinct part of the agricultural college curriculum. In the judgment of the Committee the course will have two highly important functions — (1) it will provide a basis for the accurate adjustment of credit when students leave one college to enter another and (2) it will provide a basis for improvement to which teachers may systematically contribute. The Committee considers the latter function extremely important. There is now a great opportunity for constructive work in the science of teaching our subject, and the Committee believes that if teachers can accept a common basis for future development, research in this field will be greatly stimulated.

The Form of a Standard Course.— What then should be the form of the standard course? What subject matter should be chosen? With instruction in crop production as the principal aim of the Field Crops curriculum, an introductory course may be organized in either of two forms — (1) *individual treatment*, by which crops are studied separately, according to their historical and economic significance, their ecological and botanical relationships, their physiological processes, and the cultural methods by which they are produced or (2) *general or topical treatment*, by which the history, importance, relationships, processes, and cultural methods of all crops are grouped in a *topic outline* and developed in a broad fundamental way.

A standard course organized in the first form could have only a limited adoption. Not only do crops differ, but the best methods for their production differ between various parts of the country.

[1] Presented at the meeting of the Society held at New Orleans, La., November 8, 1921. (See minutes, Vol. 13, page 367.)

And a further objection may be raised against this form on the point of efficiency in teaching. There is a great deal of wasteful repetition in a course which deals separately with individual crops. So many of the facts discussed for one crop are repeated for others. This repetition progressively lessens the interest of the student and affords no mental stimulus for the teacher himself.

Neither of these objections apply to a course which deals largely with the principal factors underlying the production of all crops. Indeed the strength of this course parallels the weakness of the course organized on the basis of individual treatment. It can be very widely adopted. It emphasizes pointedly, rather than incidentally, the fundamentals of crop production. It can systematically give the student a general grasp of these fundamentals. It can impress him with the breadth and dignity of the subject. It is efficient, in its systematic special treatment of facts fundamental to the production of all crops; and it will stimulate the interest of teachers, since it offers a broader opportunity for constructive study and individuality in presentation. And finally, it will awaken the student to a better appreciation of the value of the basic sciences, since it so frequently affords the opportunity for applications of scientific facts to practice.

Assuming the superiority of the general or topical course, the committee recommends that the standard introductory course be organized in that form, and in the following outline we suggest a body of subject matter which we believe will be satisfactory for the lectures of such a course.

A SUGGESTED OUTLINE FOR LECTURES IN A STANDARD INTRODUCTORY COURSE IN FIELD CROPS.

LECT. I. DEFINITION OF THE PURPOSE AND SCOPE OF THE FIELD CROPS CURRICULUM.

A. To give instruction in the successful production of crops.
  1. By surveying and discussing good methods and practices.
    a. Those in use by good farmers.
    b. Those that have developed from experimental evidence.
    c. Those indicated by experimental evidence.
  2. By discussing significant developments in agronomic research and investigation.
  3. By deductions and theories based on facts learned by experience and experimentation.

B. To vitalize for the student the basic sciences — botany, chemistry, physics.
  1. By explaining and illustrating the known relations of many scientific facts to good practices in crop production.
  2. By suggesting other possible relations.

C. To illustrate in a special way the influence of crops upon economic conditions.

LECT. II. CLASSIFICATION OF FIELD CROPS.

A. Botanical groups — grasses, legumes, others — and their relationships.
B. Agronomic groups — grain, forage, fiber, root, etc., etc., etc.
C. Special purpose groups — cover, catch, green manure, soiling, silage nurse, etc., etc., etc.

(In this lecture Ball and Piper's glossary of agronomic terms — see Journal, of Agronomy — should be assigned for class study and its value explained.)

LECT. III. THE ECONOMIC SIGNIFICANCE OF FIELD CROPS.

A. Crops the basis of world trade.
B. Crops the basis of farm wealth.

LECT. IV. RELATION OF GOOD CROPS TO GOOD TIMES.

A. General prosperity and progress depend upon a stable supply of cheap food.
B. Crops the most important and cheapest source of food.
  1. Why food has been cheap in the past.
    a. Free or cheap land.
    b. Cheap labor.
    c. Invention of labor saving machinery.
  2. Future production of cheap food.
    a. The maintenance of soil fertility.
    b. Improved cultural methods.
    c. Improved varieties.
    d. Control of enemies — diseases, insects, etc.
    e. Economy of labor.
C. Need of a national policy in crop production.
  1. To promote the maintenance of soil fertility.
  2. To stabilize the production and disposal of crops, so that profits may be justly distributed.

LECT. V. RELATION OF GOOD METHODS OF CROP PRODUCTION TO PROFIT.

A. Good methods and the economy of labor.
B. Relation of general high production to profit.
C. Relation of individual high production to profit.
D. Most productive methods not necessarily the most profitable.

LECT. VI. DISTRIBUTION OF FIELD CROPS.

A. As influenced by the various characteristics of climate, especially the length and nature of the growing season.
B. As influenced by the character of the soil.
C. As influenced by economic and social conditions.

LECT. VII. THE RIGHT CROP IN THE RIGHT PLACE.

A. The soil must be suitable for the crop.
  1. Choice of soil in relation to the needs of the crop to be grown. Examples and explanations.
  2. Cultural modifications of soils for crop needs.
    a. Irrigation.
    b. Drainage.
    c. Terracing.
    d. Ridging on wet lands.
    e. Listing under dry conditions of soil and climate.
B. The crop must be adapted to the climate.
  1. Requirements of important crops for the characteristics of climate.
  2. Nature and effects of drought and winter-killing.

LECT. VIII. THE VALUE OF GOOD VARIETIES.

A. Local differences between good varieties and poor ones.
B. Values of some famous varieties.
C. Range of varietal form in important crops.
  1. Varietal distinctions.
    a. Morphological.
    b. Physiological.

2. Stability of varietal distinctions.
   a. As affected by climate.
   b. As affected by soil.
   c. As affected by mixtures.

LECT. IX. PLANT IMPROVEMENT.

A. Possibilities of profit from plant improvement.
B. Methods of plant improvement.
   1. Selection — mass and pedigree.
   2. Hybridization.
C. Some notable accomplishments in plant improvement.
D. Relative importance and limitations of plant improvement.
E. Plant improvement under farm conditions.

LECT. X. THE VALUE OF GOOD SEED.

A. What is good seed?
   1. Its qualities.
   2. Conditions which affect qualities.
B. Profit in the use of good seed.
   1. Illustrations of its superior yield.
   2. Comparative value of its returns on the basis of the unit of investment.

LECT. XI. HOW TO SECURE GOOD SEED.

A. Practices in seed selection (See lecture IX).
B. Storage practices.
C. Seed testing.
D. Seed associations.
E. Seed laws, etc.

LECT. XII. PREPARATION OF THE SEEDBED.

A. Good preparation increases yield.
B. Statement and explanation of the benefits of good preparation.
C. Principles of preparation.
   1. Condition of the soil.
   2. Time of preparation in relation to climate, crop, soil type, etc.
D. Good methods of preparation for the most important local crops.

LECT. XIII. COMMERCIAL FERTILIZERS.

A. The uses and general effects of fertilizers.
B. Theories of fertilizer application.
C. Economy in the use of fertilizers.

LECT. XIV. BARNYARD MANURE.

A. Its benefit to crops and the probable reasons.
B. Economy in its use.
   1. Relative value for different crops.
   2. Time of application in relation to value.
C. Care of manure.

LECT. XV. LIME.

A. Its benefit to certain crops and the probable reasons.
   1. Crops which are benefited by lime and the general conditions under which lime should be used.
   2. Crops which are not apparently benefited by lime.
B. Commercial forms of lime.
C. Time and methods of application.

LECT. XVI. SEEDING PRACTICES.

A. Relation to kind and quality of seed.
B. Relation to climate, season, and time of seeding.
C. Relation to soil.
D. Rates and dates of seeding local crops, presented in tabular form.

LECT. XVII. GERMINATION OF THE SEED.

A. Seed structure.
B. Conditions for germination.
C. Process of germination.

LECT. XVIII. CROP GROWTH. (Optional, depending upon previous instruction in Botany.)

A. Sources of plant food.
B. Probable way in which plant food and water is taken from the soil.
C. Photosynthesis and food storage.
D. Reproduction.

LECT. XIX. CROP TILLAGE.

A. Effects of tillage.
B. Theories of tillage.
C. Tillage practices with local crops.

LECT. XX. HARVESTING GRAIN CROPS.

A. Importance of timely harvesting.
  1. Losses from over-ripe crops.
  2. Losses from under-ripe crops.
  3. The proper stage for harvesting.
B. Harvesting methods for different grain crops.
C. Comparative value of different methods of storage — shocks, stacks, ricks, bins, cribs, etc.

LECT. XXI. HARVESTING FORAGE CROPS.

A. Importance of timely harvesting.
  1. Losses from over-ripe crops.
    a. Shattering, lodging, etc.
    b. Reduction in palatability and nutritive value.
    c. Reduction in yield of subsequent cutting.
  2. Losses from under-ripe crops.
    a. Loss in nutritive value.
    b. Loss in maximum yield of dry matter.
    c. Greater difficulty in curing.
  3. The proper stage for harvesting.
    a. General rules.
    b. The proper stage for harvesting local forage crops.

LECT. XXII. HAY MAKING.

A. Essential facts about curing hay.
  1. Changes in plant material during curing process.
  2. Relation of these changes to market quality of hay.
  3. Loss of substance during curing.
B. Practices in curing local crops.
C. Summary of general rules.

LECT. XXIII. ENSILAGE.

A. Economy of ensilage.
B. Changes in plant matter, green to cured — conditions of good ensilage.
C. Ensilage crops — choice, rate of planting, stage for cutting, etc.
D. Good practice in making and preserving ensilage from important crops of the section.

LECT. XXIV. SPECIAL PURPOSE CROPS.

A. Catch crops, cover crops, green manure crops.
B. Principles in their choice and production.
  1. Early, quick growing, aggressive varieties.
  2. Cheap preparation.
C. Examples of local catch, cover, and green manure crops.

LECT. XXV. PLANT ASSOCIATION AND COMPETITION.

A. Plant association in nature.
B. Plant association (mixtures) in cultivation.
 1. How plants may benefit by association.
 2. How plants may be injured by association.
 3. Principles in choosing plants for associated growth.
 4. Examples of successful and unsuccessful associations — reasons, etc.
C. How type of population is shifted by a change in the soil.
D. Aggressiveness in plants — advantages and disadvantages.

LECT. XXVI. PASTURE MANAGEMENT.

A. Importance of pastures.
B. Classification.
C. Cultural methods.
D. Seeding.
E. Carrying capacity.
F. The leading pasture grasses — general and local.

LECT. XXVII. MEADOW MANAGEMENT.

A. Uses and purposes of meadows as distinguished from uses and purposes of pastures — value in rotations, etc.
B. Meadow mixtures.
 1. Principles and practices.
 2. Plants adapted for local use.
C. Cultural methods.

LECT. XXVIII. THE WEED FACTOR IN CROP PRODUCTION.

A. Definition — weeds a competitor of crops, etc.
B. Damages and benefits of weed growth.
C. Classification and characteristics of weeds.
 1. Root habits.
 2. Growth habits.
 3. Seeding habits.
D. Control of weeds.
 1. Cultural.
 2. Smothering.
 3. Chemical sprays.
 4. Clean seed.
E. Summary of control methods.

LECT. XXIX. CROP ROTATION (GENERAL CONSIDERATIONS).

A. Effect of continuous cropping.
B. Development of fallow and rotation systems.
C. Reasons for crop rotation.
 1. Maintenance of yields.
 2. Distribution and economy of labor.
 3. Reduction of risk.
 4. Control of weeds, insects, diseases.

LECT. XXX. CROP ROTATION (PRACTICES).

A. Essentials of a good rotation.
B. Planning the rotation.
C. Examples of good rotation with local crops.
D. Difficulties and limitations of crop rotations.

LECT. XXXI. CROP DISEASES.

A. Economic importance of diseases of crop plants.
B. Some of the most important diseases.
 1. Their nature and causes.
 2. How they are spread.
 3. Life history of an important disease fungus.
C. The control of diseases in field crops.
 1. Curative measures too expensive to be practicable.
 2. Prevention of diseases.

LECT. XXXII. INSECT ENEMIES OF FIELD CROPS.

A. Economic importance of crop insects.
   1. How and to what extent they damage crops.
   2. Life history of an important insect enemy of field crops.
B. The most important crop insects.
C. Prevention of insect attack.
   1. Rotation.
   2. Clean farming.
D. Control of insects — measures for a few important cases, selected to illustrate general principles of control.

LECT. XXXIII. GRAIN GRADING.*

A. Early establishment of grades.
   1. Faults of early grades.
   2. Conditions which led to Government investigation.
B. Federal grades.
   1. Establishment.
   2. Advantages.
   3. Processes in grading.
C. Federal supervision of grades, organization, etc.
D. Licensed and State inspectors.

LECT. XXXIV. GRAIN MARKETING.*

A. Time of marketing.
B. Transportation to local market.
C. The local market and its value.
D. The central market.

LECTS. XXXV — XLV. A SUMMARY OF INFORMATION ON THE PRODUCTION OF LOCAL CROPS.

In these lectures (XXXV–XLV) the most important local crops should be treated individually, giving to each crop the time its relative importance deserves. For example, three or four periods might be spent with corn, in which would be summarized from the general subject matter of the previous lectures all information that bears directly on good methods of corn production, together with such other practical information as the teacher wishes to include. The purpose of the summary is therefore to align, to review, and to supplement — in such a way that the student will receive definite instruction in good methods of local production, based upon the broad and fundamental considerations previously developed.

* The grading and marketing of cotton, tobacco, hay or potatoes may be substituted or added here, if desirable.

In preparing this outline the Committee requested of all departments of Agronomy or of Field Crops in the country (1) the outline of their present elementary courses or (2) their suggestions for the essentials of a standard course. Thirty-six replies were received, which number may indicate the degree of interest the matter holds for teachers in general. The majority of these replies presented the conventional outline for the individual treatment of crops; in some replies were found a few suggestions for topics similar to those composing the larger part of the outline now presented by the Committee; and the suggestions of a few teachers were decidedly in the direction of this outline. We therefore conclude that the

idea for a more fundamental introductory course is already in the minds of several teachers.

The Committee considers this outline by no means perfectly developed. *It is only an essential basis for further construction and improvement.* Details are purposely omitted, except when necessary to explain a topic heading or to illustrate the possibility of elaboration. The general purpose is to suggest and illustrate rather than to construct rigidly. Individual teachers may wish to modify some parts of the outline or to substitute other topics in conformity with local conditions. For instance, some may substitute for grain grading and marketing the grading and marketing of cotton, tobacco, potatoes, or hay; or include a general treatment of root crops; or broaden the topic "hay-making;" or reduce somewhat the economic considerations of crops (lectures III, IV, V). *Such modifications will not be contrary to our general idea, which is to deal mainly with fundamentals.* The outline is elastic enough for the reasonable adjustment of topics to local needs.

Some teachers may feel that at certain points the outline encroaches upon the subject matter of other departments. *However, it is not intended that discussions of subjects which might be classified as Soils, Botany, etc., shall proceed far into the technical fields of those departments.* For example, the discussion of lime would aim only to give the student essential information for the intelligent use of lime in crop production. To give such information must be a privilege and a duty of the course in Field Crops — a privilege, because we may properly deal with all the essentials of crop production; a duty, because many of our freshmen or sophomore students may not reach courses in other departments which deal specially with some of these vital subjects.

In suggesting this outline the Committee assumes that the standard course will be taught to freshmen or sophomores, that its presentation will require three lecture periods weekly during one scholastic term; that it will be supplemented by two laboratory periods, thus completing a five-hour course; and that it will be followed by advanced special electives, such as Grain Crops, Forage Crops, Fiber Crops, Field Crops Improvement, and Field Crop Management.

The Committee wishes to emphasize its allotment of 10 or 12 lectures for the treatment of individual crops in the latter part of the course. These special lectures will serve the double purpose of applying the fundamentals previously studied and of giving specific instruction in the production of local crops. The Committee believes this number will generally be sufficient, in view of

the previous study of fundamentals common to all crops, but it may be somewhat increased to serve local needs and the number of general topics adjusted accordingly.

Respectfully submitted.

W. C. ETHERIDGE,
M. L. FISHER,
COMMITTEE ON LECTURES FOR A STANDARD INTRODUCTORY COURSE IN FIELD CROPS

NITROGEN ECONOMY IN SOILS[1]

FIRMAN E. BEAR.[2]

COMBINED NITROGEN IN RAINWATER.

After listening to Liebig's lectures before the British Association for the Advancement of Science in 1840, Lawes and Gilbert returned to Rothamsted with the determination of testing the accuracy of his conclusions as to the sufficiency of the ammonia of the atmosphere as the source of the nitrogen of plants. Accordingly, arrangements were made for collecting the rainfall on a measured area with the result that the total combined nitrogen thus secured was estimated at 6 or 7 pounds per acre. Later, more exact determinations summarized by Russell and Richards (30)[3] and covering the period from 1888 to 1916 showed an average acre content of ammoniacal and nitric nitrogen in the rainfall amounting to 3.97 pounds. To this may be added that recorded as being in organic forms and estimated at 1.35 pounds per acre, making a total of 5.32 pounds from an average rainfall of 28.8 inches.

A review of the literature on this phase of the subject by Wilson (34) shows the nitrogen content of rainwater has usually been found to be from 5 to 8 pounds per acre annually. Occasional reports have indicated much larger quantities amounting to as much as 15 to 20 pounds. In his investigations at Ithaca, New York, covering the period from 1915 to 1920, Wilson found an average of 12.51 pounds per acre of ammoniacal and nitric nitrogen with a rainfall of 29.3 inches. It is questionable as to how correctly this average figure may represent the nitrogen in the rainfall. It is possible

[1] Paper read at the meeting of the Society held at New Orleans, La., November 7, 1921.

[2] Professor of Agricultural Chemistry and Soils, Ohio State University, Columbus, Ohio.

[3] Reference by number is to "Literature Cited," p. 151.

that the high quantities noted for three years may be related to the enlarged industrial activities associated with the World War. For the two-year period from May, 1918, to May, 1920, the average was slightly less than 4 pounds per acre. Ames (1) reports the nitrogen content of the rainwater at Wooster, Ohio, at from 6 to 7 pounds per acre, with an average rainfall of 37.9 inches.

No very definite correlation is apparent between the amount of combined nitrogen in the rainwater and any contributing agent. In general it may be said that the amount tends to be larger with the increased rainfall and perhaps also with the nearness to industrial centers. Probably the quantity obtained over much of the humid sections of America would amount to not more than 5 to 6 pounds per acre annually.

FIXATION OF ATMOSPHERIC NITROGEN.

Ever since Wilfarth (33) reported the quantity of nitrogen contained in the inoculated as compared to the uninoculated lupins which he grew in pots filled with sand, investigators have been studying the efficiency of *B. radicicola* as a nitrogen fixing organism. The experiments designed to determine this have fallen largely into three groups:

1. Comparisons of the nitrogen content of legumes and non-legumes grown on equal areas of similar soil.
2. Comparisons of the nitrogen content of inoculated and uninoculated legume crops grown on equal areas of similar soil.
3. Analytical records of the nitrogen content of the soil of a given area before and after the growth of the legume, together with records of the nitrogen in the seed and water added and that removed in the crop and drainage water.

COMPARISONS OF THE NITROGEN CONTENT OF LEGUMES AND NON-LEGUMES.

As early as 1860, Lawes and Gilbert (22) pointed out that legume plants contained much larger amounts of nitrogen than non-legumes grown on the same soil. As an average of three years data, they had found the nitrogen content of the cereal crops at Rothamsted to be approximately 30 pounds per acre as compared to 120 pounds contained in clover. They wrote:

> "Ammonia cannot be procured in the market in any large quantities, but by cultivating turnips and the leguminous plants, a large amount of this substance is collected by them from the atmosphere."

However, the difference in nitrogen content of a legume and any given non-legume grown on the same land may not represent the nitrogen gained thru the agency of the legume and its associated

organisms, since the several non-legumes differ markedly in their capacity to take nitrogen from the soil. Hiltner (20) classifies the non-legumes into two groups, the "Stickstoffzehrer" and the "Stickstofferhalter" and of the latter group mentions in particular the rape plant. Analyses recorded by Henry and Morrison (19) show that this plant, in common with several well-known weeds such as purslane and field daisies, may contain percentages of nitrogen equal to or greater than that of red clover.

In this connection, the conclusion of Lyon and Bizzell (26), that the rate of nitrification in soils is very much influenced by the growing crop, is pertinent. Maize and clover were shown to have markedly stimulating effects on nitrate formation. Timothy and some of the grasses were found to depress nitrification. Of particular interest is the possibility that legumes, by reason of their favorable effect on nitrification, may thereby be enabled to secure larger amounts of nitrogen from that stored in the soil organic matter than is ordinarily supposed. If the comparison is to be between a legume and a non-legume perhaps a member of the "Stickstofferhalter" group should be selected.

COMPARISONS OF THE NITROGEN CONTENT OF INOCULATED AND UNINOCULATED LEGUMES.

Numerous examples of this type of investigation are found in the literature. Among the more recent may be mentioned the data reported by Arny and Thatcher (3) on first crop, second season, sweet clover and alfalfa grown on moderately productive soil. In their tests, it was shown that the nitrogen content of the former, calculated from the tops and roots produced on plots of three square yards, was increased at the rates of 133 and 76 pounds per acre by inoculation with and without an accompanying use of lime respectively. Similarly, 118 more pounds of nitrogen per acre were found in inoculated than in uninoculated alfalfa. Fred (12) found an increase from inoculation in the nitrogen content of the tops, roots and nodules of soybeans, calculated from the crops grown on areas of 137.5 square feet of Plainfield sand, amounting to 57 pounds per acre.

Such a method of calculation would apparently not exaggerate the nitrogen fixing capacity of the nodule organisms, since it is difficult to find an area of the legume crop which is not at least partially inoculated. However, the foraging power of the legume plant for soil constituents must be considerably increased as a result of the larger growth following inoculation. The work of Arny and Thatcher shows that not only are the quantities of the mineral

constituents in legumes thus increased, but that the actual percentage of potassium may be larger. The increase in the nitrogen content of legumes may therefore, represent a saving as well as a fixation. Taken in connection with the fact that legumes stimulate nitrification, this would throw considerable doubt on the validity of the argument that differences in nitrogen content due to inoculation represent the fixation by the nodule organisms of legumes.

The following conclusion of Hopkins (21) drawn from this type of investigation is interesting in this connection:

"On normally productive soils, one third of the nitrogen contained in legumes is taken from the soil, not more than two thirds being secured from the air"

COMPLETE ANALYTICAL RECORD OF NITROGEN ECONOMY IN THE SOIL AND CROP.

Of the more exact methods involving analyses of the soil, seed, and water, and of the crops removed, the pot tests of Hartwell and Pember (18) deserve particular mention. These investigators studied the nitrogen economy in Warwick sandy loam soil accompanying the growth of cowpeas, soybeans, crimson clover and adzuki beans, using vetch as a winter cover crop. Most satisfactory growth was reported for the first two. Summarizing their investigations they wrote:

"The approximate five-year net gain of nitrogen in the presence of these two crops, and the vetch which was grown alternately with each, was a ton of nitrogen per acre, about seven tenths of which was contained in the twenty-five tons of moisture free summer crop removed, and the remainder in the soil itself."

This indicates that the fixation processes may be quite rapid where the conditions are kept at or near the optimum. The original soil contained 0.1502 per cent of nitrogen. That in the soybean pots had a nitrogen content of 0.1987 per cent and of the cowpea pots of 0.1944 per cent at the end of the 5 year period. A point would probably soon have been reached at which the legume would have made larger use of the nitrogen previously fixed and made available thru nitrification.

NON-SYMBIOTIC PROCESSES.

The quantitive relationships which obtain in nitrogen fixation were found to be somewhat complicated when it was discovered by Winogradski and Beyerinck that certain of the organisms in soils, other than those which were known to produce nodules on the roots of legumes, were able to assimilate atmospheric nitrogen. Of these the *Azotobacter* group is credited with the greatest capacity. The conditions favoring their activities are now known to be quite similar to those suited to legume crops and include the presence of available phosphorus and potassium, carbonaceous materials and carbonates of calcium or magnesium, the latter according to Ashby

(4) appearing to be preferabl[illegible] capacity of these organisms to accumulate nitrogen under field conditions. Perhaps the statement of Lipman (23) has been most frequently mentioned in this connection:

"From the data at present available different investigators have estimated the quantity of nitrogen fixed by Azotobacter at 15 to 40 pounds per acre per annum."

The quantity of nitrogen assimilated from the air by non-symbiotic organisms is probably dependent, among other factors, upon the nitrate content of the soil. Nitrification is also favored by conditions similar to those suited to the needs of *Azotobacter*. Bonazzi (7) has recently shown that the presence of nitrates aids in the better utilization of the carbohydrates usually supplied in nitrogen fixation studies. It is his opinion that *Azotobacter* serve as nitrate conservers and that after the available nitrates have been utilized "a second physiological phase sets in, in which the cells assimilate atmospheric nitrogen." He writes further:

"It appears that 'all' organisms choose the line of least resistance for obtaining and assimilating their food; and micro-organisms are not an exception to the rule."

Investigations reviewed and extended by Fred (13) have shown that *B. radicicola* has the capacity to fix atmospheric nitrogen in the absence of its host. The experiment of Golding (15) in which the rate of fixation was increased by the removal of the soluble products of growth as produced indicates that this process might be considerably increased in the presence of growing plants which were withdrawing the nitrogen as it became available thru fixation processes. Even when the *B. radicicola* are working symbiotically the presence of a non-legume to serve in the removal of soluble nitrogen from the soil may be found desirable. A review of the data on this point together with supplementary investigations by Wright (35) indicates that it is not safe to assume, however, that the association of legumes and non-legumes always guarantees an increased nitrogen content of the non-legumes or an increased rate of fixation by the legume and its nodule organisms.

THE LYSIMETER METHOD OF STUDY.

Of all the methods employed in the study of the nitrogen economy of soils that in which use is made of lysimeters is perhaps to be preferred. Such tests approach somewhat more nearly to field conditions and yet provide for the checking up of the nitrogen outgo in the drainage water. An interesting record under such conditions of the nitrogen economy in Dunkirk clay loam soil having a nitrogen content in the first foot of 0.134 percent is provided by the work

of Lyon and Bizzell (27). In [illegible] the rate of loss of nitrogen in drainage from the manured soil was correlated rather definitely with the quantity of drainage water. The rather surprising feature of these investigations thus far is the relatively small amount of nitrogen in the drainage from cropped lysimeters. Excluding the first year, in which the loss was abnormally high due to the f[illegible]ct that the soil had been disturbed in moving and oxidation was probably considerably increased as a result, the average annual loss amounted to only 3.4 pounds per acre. Another important feature is the apparent confirmation of their conclusions, previously referred to, which indicate that the rate of nitrification is definitely related to the kind of crop being grown. For example, it was shown that the nitrogen losses in drainage were least in the presence of mixed grasses altho the nitrogen removed by them from the soil, as shown by analysis, was smallest of any of the crops under observation. In the absence of vegetation the nitrogen losses averaged nearly 100 pounds per acre annually, equal to half of the quantity applied in the form of manure.

The texture of the soil is a very important factor in determining the rate of nitrification and the subsequent loss of the nitrates in the drainage water. For this reason the problem is most serious in sandy soils, especially if they happen to be in a warm climate. The possibilities of losses under such conditions are shown in the lysimeter tests in Florida, as reported by Collison and Walker (9). However, as this experiment progressed and the trees in the tanks grew larger, the losses were very considerably curtailed by reason of the facts that a large part of the soil water was returned to the air by transpiration and more nitrate was utilized by the trees.

It is apparent that, in addition to the climatic and soil factors, the system of management which the soil receives will determine to a very large degree the point at which the drainage losses and the fixation processes will come to equilibrium. Nitrogen fixation is known to be stimulated by the use of potassium and phosphorus fertilizers and by the application of lime or limestone. In unproductive soils nitrogen fixation will be slow, but the nitrification processes are likely to be correspondingly slow. To accumulate nitrogen in the soil, nitrification need not necessarily be stopped, but both conserving and fixation processes must be in operation. It may also be possible, as suggested by Lyon (25) to grow acid tolerant legumes on soils in which nitrification has been retarded and thereby accumulate nitrogen. The critical pH of the nodule organisms of the soybean, for example, was found by Fred and

Davenport (14) to be 3.4 [illegible] red clover and 5.0 for those of sweet clover and alfalfa. Salter finds that the critical point in the soil is approximately 1 pH higher than would be expected from culture solutions, due probably to the toxicity of the soluble aluminium. This would place the critical pH for nodule organisms of soybeans at 4.4. Nitrification in an acid DeKalb soil was found not to be accelerated to any considerable extent until the pH had been raised to 6, with a maximum between 6 and 8. It is possible, therefore, that a degree of acidity could be selected at which nitrogen accumulation could continue with a minimum loss of nitrate.

CYLINDER STUDIES.

When soils which are high in nitrogen are placed under cultivation the nitrogen content is rapidly reduced, because the nitrogen fixation processes cannot keep pace with the excessive nitrification and because even the legume crops do not require any considerable amount, if any, of nitrogen other than the nitrates produced. The nitrogen economy under such conditions is very nicely shown in the cylinder tests which have been carried out at the New Jersey Station (24). These studies were made on a light loam soil having an original nitrogen content of 4,975 pounds per acre ten inches. The cropping system was corn, oats, oats, wheat, timothy. From 1898 to 1907 the nitrogen content of the soil was reduced, on the phosphate and potash-treated cylinders, to 3,560 pounds. This represents a loss of 1,415 pounds of nitrogen of which only 415 pounds was accounted for in the crops removed.

Beginning with 1908, one series of cylinders was limed and fertilized with phosphate and potash salts and in addition a legume catch crop was turned under twice each five-year period. In this series the nitrogen content was reduced from 3,716 in 1908 to 3,274 in 1912, a loss of 442 pounds of which 231 was accounted for in the crops removed. By 1917, the nitrogen content of the soil had been reduced to 3,135 pounds, a further loss of 139 pounds. However, during this period the quantity of nitrogen removed in the crops amounted to 287 pounds. Apparently the point of equilibrium between nitrogen income and outgo had very nearly been reached.

NITROGEN ECONOMY STUDIES IN FIELD SOILS.

It will probably always be desirable to give our conclusions a final field test. Fortunately, it happens that crop records accompanying the regular and long continued use of fertilizing materials and definitely planned rotations are now available covering long periods of time, particularly at the Rothamsted, Pennsylvania and Ohio

experimental farms. It would ... to check our conclusions on nitrogen economy by an investigation of the soils of these plots.

In 1885, Hall (16) called attention to what appeared to be a rather remarkable increase in the nitrogen content in soils allowed to run wild on the Rothamsted farm. Analyses of soil to a depth of 27 inches from such areas in the Broadbalk and Geescroft fields, before and after a twenty-year interval, showed an apparent average annual gain of 98 pounds per acre in the former and 44 pounds in the latter. The data were all the more remarkable when it was shown that the percentage of legume plants in the Geescroft field at the last sampling date was less than one-half of one percent.

It is interesting in this connection to examine the records of analyses of the soil of plot 5 of the continuous wheat series in Broadbalk field. This plot has received a complete mineral fertilizer but no nitrogen since 1852. Analyses of the soil were made in 1865, 1881, 1893 and 1914. Data for the first three analyses are given by Dyer (11) and for the last by Russell (29). They are as follows:

TABLE 1.—*Estimated acre content of nitrogen of Broadbalk soil—complete mineral fertilizer plot—continuous wheat.*

Date.	First 9 inches.	Second 9 inches.	Third 9 inches.
1865	2782	1910	1708
1881	2543	1865	1597
1893	2517	1827	1563
1914	2517	1827	1680

The method of sampling in 1914, according to Russell, was comparable with that of previous samplings in so far as it applied to the surface 9 inches, but slightly different in the second and third depths. Considering only the first depth, the nitrogen loss amounts to 265 pounds per acre in a period of 50 years or a little over 5 pounds per acre per year. Crop records available for the 50-year period 1862–1911, which should be quite similar to those for 1865 to 1914, show that the average yield on this plot during this period has been 13.9 bushels of wheat and 11.2 hundred weight of straw, totaling 695 bushels of wheat and 560 hundred weight of straw, per acre. Subtracting 100 bushels of seed wheat would leave 595 bushels. With an estimated nitrogen content of 1.78 per cent for the grain and 0.475 for the straw, the total nitrogen removed by the crops during this period must have amounted to a little over 900 pounds or 19 pounds per acre per year.

Hall (17) estimated the annual drainage loss of nitrogen from this plot for the two years 1879–81 at 16.7 pounds per acre. This is

probably too high. The rate of loss has probably also decreased during more recent years. However, the drainage loss must certainly have equalled the gain in the rainfall, amounting to 5.32 pounds per acre. Even in the absence of legume crops, except the black medick which grows as a weed on these plots, and under conditions not particularly adapted to economizing in nitrogen, the assimilating process has kept pace with the removal after the total nitrogen content had fallen to approximately 2,500 pounds per acre-nine-inches.

In 1916, Bear and Salter (6) called attention to what appeared to be an increase of nitrogen amounting to 1,173 pounds per acre to a depth of 20 inches which had been accumulated in the soil of a plot on the West Virginia Experiment Station farm which had been liberally treated with phosphate and potash fertilizers and cropped in rotation for a period of 16 years. This figure was obtained from a consideration of the probable amount of nitrogen contained in the crops removed and from a comparison of the nitrogen content of the soil on this plot with that of an adjacent check. This accumulation, amounting to 73 pounds per acre per year, which may represent a saving as well as a fixation, had taken place in a silt loam soil having a nitrogen content of approximately 2,000 pounds per two million of surface soil, under conditions in which a legume crop was grown every fourth year. An interesting phase of this investigation was shown in the fact that there was almost a direct correlation between the phosphorus, nitrogen and carbon content of the soils of all the plots at the end of this period. This correlation was found to obtain in analyses of 240 soils chosen from various sections of West Virginia, a high content of phosphorus being invariably associated with high nitrogen content.

Later, from an examination of the records of the crop yields on similarly fertilized series at Wooster, Ohio, which had received additional applications of lime, the writer concluded that nitrogen fixation had progressed on these plots during the 25 year period of the test to the extent of 1,100 pounds per acre or 44 pounds per acre per year. Analyses of the soil were not then available. Since that time Ames (1) has reported the nitrogen content of the soil on plot 8 of section D of this series from samples chosen at several different time intervals. It seems desirable, therefore, to recalculate the data for the period since 1904, when the first application of lime was made. The record for the plot shows that it was in corn in 1904, oats 1905, wheat 1906, clover 1907 and timothy 1908 with the same crop sequence from that date forward, yields being available up to and including the wheat crop of 1921. The corn, oats, and wheat

have each been fertilized with acid phosphate and muriate of potash in amounts per acre totaling, for the period, 1,280 pounds of the former and 1,040 pounds of the latter. The west half of this plot was limed in 1904 and has been relimed as needed since. The east half of the plot has not received any lime. The following table gives the actual yields of crops for the period and the estimated number of pounds of nitrogen contained in them, calculated on the acre basis.

TABLE 2.—*Estimated nitrogen content per acre of crops removed—phosphate and potash treated plot—Wooster, 1905–21.*

		West half limed.		East half unlimed.	
Crops.	Frequency.	Yield, hundred weight.	Nitrogen, pound.	Yield, hundred weight.	Nitrogen, pound.
Corn	4	126.3	190.3	84.3	126.9
Stover	4	83.8	68.2	64.8	52.7
Oats	4	75.5	152.0	63.6	128.1
Straw	4	102.1	59.3	87.5	50.8
Wheat	4	64.5	127.4	44.7	88.4
Straw	4	100.6	53.1	61.2	32.3
Clover	3	97.1	210.5	33.5	72.7
Timothy	3	129.9	109.2	71.2	59.9
Totals		779.9	970.0	510.8	611.8

In estimating the nitrogen content of the crops removed, the average analyses of crops as reported by the Chemistry Laboratory of the Ohio Agricultural Experimental Station were employed. Ames, Boltz and Stenius (2) have shown, in a study of wheat samples selected from the several plots receiving various fertilizer treatments, that the nitrogen content of the wheat from the plot receiving phosphate and potash salts was only approximately 90 per cent of the average. Using this factor on all of the crops, the above figures for nitrogen would have to be corrected to 873 and 550 respectively.

On examining the records of the analyses of soil, it is found that this plot was sampled in 1907 and 1912. On request, Ames resampled the plot in 1921. The records of these analyses are given below:

TABLE 3.—*Estimated nitrogen content per acre of Wooster soil—phosphate and and potash treated plot.*

Dates.	West half limed, pounds per acre*	East half unlimed, pounds per acre*
1907	2000	1860
1912	2060	1680
1921	1846	1660

* On basis of 2,000,000 of surface soil.

The 1921 sample shows a reduction in nitrogen. To be strictly comparable to the samples chosen in 1907 and 1912, the sampling should have been delayed to 1922 which is the year in which the clover crop is being grown, the sampling having always followed the removal of the clover crop. Assuming the usual benefit supposed to be derived from a good crop of clover on well fertilized and limed soil, it would again seem reasonable to believe that the nitrogen content of the limed soil was being maintained at approximately a constant level approaching 2,000 pounds per acre. The point of equilibrium in the unlimed soil under the conditions of the test was apparently reached at a point approximating 1,650 pounds of nitrogen.

Accepting this assumption, it would appear that nitrogen accumulation since 1904 had been proceeding on the limed end of this plot at a rate of 58 pounds per acre per year. To this must be added that which was lost in the drainage. From this must be subtracted that secured from the rainfall. Ames reports from 6 to 7 pounds per acre annually in the rainwater. That lost in the drainage will never be known. The lysimeter tests at Cornell would indicate that it was not in excess of 3.4 pounds per acre. From data reported by Dole and Stabler (10) and by Clarke (8) it is possible to check the accuracy of the lysimeter test as applied to large areas of land in Ohio. From their data, the amount of nitrogen in the Miami River above Dayton, in the limestone area of Ohio, as determined for the year 1906-07, indicated an annual acre loss from the soils of that watershed amounting to 4.4 pounds per acre. Similarly in the Muskingum River above Zanesville, in the sandstone and shale area of Ohio, the nitrate nitrogen amounted to 1.13 pounds per acre as applied to the entire watershed. The percentage of cultivated land is considerably higher in the watershed of the Miami. This is also true of the nitrogen content of the soil. By this method of calculation the estimated loss would at least not be too high. The results of the calculation indicate that on the whole the soil is rather economical with its nitrogen supply, as the lysimeter tests indicate, and that the loss in this manner has not kept pace with the gain in the rainfall.

White (32) reports analyses of the soil of two plots (15 and 24) of the fertilizer series on the Pennsylvania State College Farm. Plot 24 is one of the check plots, while plot 15 has been receiving phosphate and potash fertilizers. The rotation followed has been corn, oats, wheat, and clover. Subtracting the crop yields of the check plot from the phosphate and potash plots and calculating

the nitrogen removed in these increases gives an estimated total of 605 pounds per acre for the 35 year period.

Analyses of the soils show a nitrogen content of 0.130 per cent for that of plot 15 and 0.1525 per cent for that of plot 24. Assuming a weight of two million pounds per acre, gives a difference of 450 pounds per acre in favor of the phosphate and potash plot. This makes a total of 1,055 pounds of nitrogen unaccounted for. Either the larger crops produced from the use of fertilizer conserved the nitrogen of the soil more successfully or a nitrogen fixation which may have amounted to an average of over 30 pounds per acre per year was in progress.

The recent report of the nitrogen content of the soil on the plots of the fertilizer series at the Missouri station (28), after 25 years of cropping, is significant as indicating the tendency of certain crops to economize on the soil nitrogen. As would be expected from Lyon and Bizzell's conclusions, the nitrogen content under continuous cropping was maintained at the highest level on the timothy plots, second on the oats and wheat plots and third on the corn plots. Incidentally these results also indicate that considerable nitrogen fixation must have occurred in the soil of the rotation series plots where no fertilizers were used, otherwise the nitrogen content in the soil should have been very greatly reduced, as compared to the virgin soil, thru its removal in crops and in increased drainage losses. The actual loss recorded at the end of the 30 year period is given at only 10 pounds per acre foot below the 4,000 pounds in the virgin soil.

The investigations of Swanson (31), in which analyses are reported of the soils of old alfalfa fields as compared to nearby native sod, have been quoted by several writers as indicating that the nitrogen fixation processes had shown no cumulative effect. The remarkable feature of the data is brought out when the quantity of nitrogen which must have been removed in the alfalfa crops harvested is taken into consideration. Evidently the point of equilibrium was reached at a nitrogen content which made the alfalfa secure a large percentage of its nitrogen requirements from the soil air. This point of equilibrium occurred under Kansas conditions at an average of 3,650 pounds of nitrogen per acre seven inches of soil.

SAMPLING FIELD PLOTS.

There are certain well recognized difficulties involved in such methods of study, which throw doubt on the quantitive accuracy of the conclusions drawn. The method of sampling plots has never been standardized. Samples of soil selected from field plots in

the early days of already long continued tests could probably not have been duplica[illegible]d, by the [illegible] employed, even the same day. [illegible] made a detailed study of the nitrogen [illegible] as it might have been reported from a variety of possible combinations in the selecting of the composite for analysis. The plots were resampled a few days later and the results compared with those previously secured. Altogether 720 separate nitrogen determinations were made. The investigation showed conclusively that the sampling of a plot can be duplicated the same day with considerable accuracy if sufficient borings are taken and the same number and location of borings are again selected. In most cases the analyses were almost exact duplicates or varied only from 20 to 40 pounds per two million of soil.

The selection of samples of soil after a period of years to correspond to those originally secured from the same plot is a difficult matter. Nevertheless, it seems to the writer that where plot areas are bordered with permanent sod strips or other precautions are taken to insure that the soil is confined to the original area, the difficulty is not insurmountable. Where plot treatments are begun and continued over long periods of time it seems highly desirable to measure rather accurately the quantitative outgo of not only nitrogen but also of other elements, as compared to the rate at which they are replaced. It must, of course, be recognized that certain movements of the soil itself or of substances in solution continue to take place. The action of water, wind, earthworms, insects and other agencies, while perhaps relatively insignificant in any one year, in most cases, may over long periods of time effect considerable changes in the soil. In the study of the number of earthworms in the soil we have found them present, in plots of soil on the Ohio State University farm which were covered with bluegrass, in numbers averaging over one million per acre. These were concentrated, at the time the numbers were estimated, in July, in the upper foot of soil. A part of the nitrogen accumulation on the land allowed to run wild at Rothamsted may be due to the fact that these undisturbed areas provided very convenient places for the concentration of the insect and animal population from nearby locations.

It is well to remember, however, that Wilfarth's original experiments showed that the entire nitrogen requirement of the lupin, under the conditions of the test, must have been taken from the air. This has been confirmed with other legumes when grown under laboratory control in the absence of all nitrogen save that in the seed.

It has also been very definitely established that the non-symbiotic organisms are not dependent upon any combined nitrogen but can effect nitrogen fixation in media entirely free from this element. The addition of a nitrate usually increases the growth of the inoculated legume and results in a marked increase in the development of *Azotobacter*. Apparently the nitrogen fixation processes are not sufficiently rapid to supply the legumes or its associated symbiotic and non-symbiotic organisms with all of the nitrogen which they could utilize in their growth processes. The ratio of the quantity which must be supplied thru nitrification processes to that which the nitrogen fixing organisms can secure from the air undoubtedly varies with the different legumes and with the conditions under which they are grown.

An examination of virgin soil will show that the largest quantities of nitrogen have been accumulated in swamps and in regions of rigidly cold and long winters. In either case, nitrification is practically at a standstill while nitrogen accumulation from the rainfall and from the fixation processes, while slow, may continue. These accumulations may represent vast expanses of time so that the quantity added each year may have been relatively small. The agriculturist is interested in nitrogen economy under conditions suitable to the growing of field crops in which case both the nitrification and nitrogen fixation processes are in operation with an equilibrium which may be established at any number of different points depending upon a variety of factors.

CONCLUSIONS.

The point of equilibrium between nitrogen income and outgo in soils varies with many factors. Temperature, rainfall, soil reaction, cropping system, fertilizer treatment and soil texture are some of these factors. In northern latitudes with a cool climate, the nitrifying process is slower but there is undoubtedly a corresponding reduction in the rate of nitrogen fixation. In southern latitudes nitrification is more rapid and, with indifferent cropping systems, the total nitrogen content of the soil may be reduced to a very low point. With the adoption of suitable rotations, accompanied by a logical fertilizer program, nitrogen fixation processes are likely to be sufficiently rapid to compensate for the greater loss of nitrates in the drainage. With rather ordinary farming methods, nitrogenous fertilizers are likely to be more effective in Michigan, Wisconsin and the Dakotas or in Florida, Louisiana and Texas than they are in Ohio, Illinois and Iowa.

As the soil reaction becomes increasingly acid the rate of nitrification is reduced. Here again a corresponding reduction in nitrogen fixation is likely to occur. In such cases it may be possible, by the selection of a legume crop which is not so sensitive to acid soil conditions, to actually accumulate nitrogen more rapidly than would be possible if conditions favored rapid nitrification. The accumulation of nitrogen is not so important, however, as that it be usable and the conditions for crop growth are usually best satisfied when the nitrification and fixation processes are both rapid and properly balanced.

Judging from laboratory tests the most rapid combined fixation will occur under conditions in which the soil is kept neutral or slightly alkaline in reaction and in which the crop rotation has included regularly a legume crop which has been stimulated to large growth thru the use of phosphate and potash fertilizers. As the quantity of nitrogen in the soil increases a point will finally be reached at which the losses sustained equal the lessened rate of fixation due to the tendency of the nitrogen assimilating organisms to take the path of least resistance in their search for this element.

The division of nitrogen-fixation between the symbiotic and non-symbiotic groups cannot readily be estimated. The evidence indicates, however, that the non-symbiotic processes are responsible for a considerable part of the nitrogen fixed under field conditions. This does not mean that they are any more efficient but that they have the advantage of the time element since they are assumed to be more or less constantly at work while the legume organisms cannot function to best advantage except in the presence of their host. Apparently the *Azotobacter* are more seriously disturbed by acidity than most of the nodule organisms. Under these conditions their function may be taken over by certain nitrogen assimilating molds which find a favorable environment in acid soils.

Under what might be considered average cropping systems, the nitrogen gains and losses in the average soil in the latitude of Ohio apparently come to equilibrium at a nitrogen content of about 2,000 to 3,000 pounds per two million of surface soil. Fluctuations above or below this quantity are dependent largely upon the climate and upon the attention which the problem receives at the hand of the farmer. The use of phosphate and potash fertilizers apparently enable the nitrogen fixing organisms to satisfy the nitrogen requirements of larger crop yields, but if the crops are removed the point of equilibrium in the soil is disturbed but little. If there is an accumulation of phosphorus either as a result of its application or

for any other reason, the point of equilibrium will be raised to correspond to the increased content of this element. The only correlations with the nitrogen content which have been established are those of the content of phosphorus and of organic matter in soils of the same type and under similar climatic and cultural conditions.

LITERATURE CITED.

1. AMES, J. W. Supply of nitrogen in the soil. Ohio Agr. Exp. Sta. Mo. Bul., v. 5, p. 174–178, 1920.
2. AMES, J. W., BOLTZ, G. E., and STENIUS, J. A. Effect of fertilizers on the physical and chemical properties of wheat. Ohio Agr. Exp. Sta. Bul. 243, p. 585, 1921.
3. ARNY, A. C., and THATCHER, R. W. The effect of different methods of inoculation on the yield and protein content of alfalfa and sweet clover. *In* Jour. Amer. Soc. Agron., v. 9, p. 135–136, 1917.
4. ASHBY, S. F. Some observations on the assimilation of atmospheric nitrogen by a free-living soil organsim, *Azotobacter chroococcum*, by Beyerinck. *In* Jour. Agric. Sci., v. 2, p. 34–51, 1907.
5. BEAR, F. E. and MCCLURE, G. M. Sampling soil plots. *In* Soil Sci., v. 9, p. 65–75, 1920.
6. BEAR, F. E. and SALTER, R. M. The residual effects of fertilizers. West Va. Agr. Exp. Sta. Bul. 160, p. 18, 1916.
7. BONAZZI, A. Studies on *Azotobacter chroococcum* Beij. *In* Jour. Bact., v. 6, p. 331–369, 1921.
8. CLARKE, F. W. Data of geological chemistry, U. S. G. S. Bul. 616, p. 78, 1916.
9. COLLISON, S. E. and WALKER, S. S. Losses of fertilizers by leaching. Fla. Agr. Exp. Sta. Bul. 132, p. 10–13, 1916.
10. DOLE, R. B. and STABLER, H. Water Supply Paper No. 234 U. S. G. S. p. 78, 1909.
11. DYER, B. Results of investigations on the Rothamsted soils. U. S. D. A. Off. Exp. Sta. Bu. 106, 1902.
12. FRED, E. B. The fixation of atmospheric nitrogen by inoculated soybeans. *In* Soil Sci., v. 11, p. 470, 1921.
13. ———. Assimilation of nitrogen by different strains of *B. radicicola* in the absence of the host plant. *In* Ann. Rep. Vir. Agr. Exp. Sta. p. 132–134, 1908.
14. FRED, E. B. and DAVENPORT, AUBREY. Influence of reaction on nitrogen assimilating bacteria. *In* Jour. Agric. Res., v. 14, p. 331, 1918.
15. GOLDING, JOHN. Importance of removal of products of growth in assimilation of nitrogen by organisms of the root nodules of leguminous plants. *In* Jour. Agric., Sci., v. 1, p. 59, 1905.
16. HALL, A. D. On the accumulation of fertility by land allowed to run wild. *In* Jour. Agr. Sci., v. 1, p. 241–249, 1905.
17. ———. The Book of the Rothamsted Experiments, Dutton and Co., p. 235, 1917.
18. HARTWELL, B. L. and PEMBER, F. R. The gain in nitrogen during a five-year pot experiment with different legumes. R. I. Agr. Exp. Sta. Bul. 147, p. 14, 1911.

19. HENRY, W. A. and MORRISON, F. B. The Henry Morrison Co., Madison, Wis., p. 601, 1915.
20. HILTNER, L. Stickstoffmehrer and stickstoffzehrer. *In* Lafar Handbuch der Technischen Mykologie. Jena. p. 21, 1906.
21. HOPKINS, G. G. Soil Fertility and Permanent Agriculture. Ginn and Co., Boston. p. 217, 1910.
22. LAWES, J. B., and GILBERT, J. H. On the sources of nitrogen of vegetation. *Abs. in* Proc. Roy. Soc. Lond., v. 10, p. 544, 1860.
23. LIPMAN, J. G. Micro-organisms as a factor in soil fertility. Marshall's Micro-biology, Blakiston's Sons and Co., Philadelphia. p. 343, 1917.
24. LIPMAN, J. G. and BLAIR, A. W. Nitrogen losses under intensive cropping. *In* Soil Sci., v. 12, p. 1–21, 1921.
25. LYON, T. L. Influence of higher plants on bacterial activities in soils. *In* Jour. Amer. Soc. Agron., v. 10, p. 313–322, 1919.
26. LYON, T. L. and BIZZELL, J. A. Some relations of certain higher plants to the formation of nitrates in soils. Cornell Agr. Exp. Sta. Mem. 1, p. 111, 1913.
27. ———. Lysimeter Experiments. Cornell Agr. Exp. Sta. Mem. 12, p. 36, 1918.
28. MILLER, M. F. and HUDELSON, R.R. Thirty years of field experiments with crop rotation, manure, and fertilizers. Mo. Agr. Exp. Sta. Bul. 182, p. 20, 1921.
29. RUSSELL, E. J. Letter from Rothamsted Agr. Exp. Sta. Oct. 4, 1921.
30. RUSSELL, E. J. and RICHARDS, E. H. The amount and composition of rain falling at Rothamsted. *In* Jour. Agric. Sci., v. 9, p. 309–338, 1919.
31. SWANSON, C. O. The effect of prolonged growing of alfalfa on the nitrogen content of the soil. *In* Jour. Amer. Soc. Agron., v. 9, p. 305–315, 1917.
32. WHITE, J. W. Letter from Pa. Agr. Exp. Sta. Oct. 4, 1921.
33. WILFARTH. Uber stickstoffaufnahme der pflanzen. *In* Land. Vers. Stat v. 34, p. 460–61, 1887.
34. WILSON, B. D. Nitrogen in the rainwater at Ithaca, New York. *In* Soil Sci., v. 11, p. 101–111, 1921.
35. WRIGHT, R. C. Nitrogen relations of certain crop plants when grown alone and in association. *In* Jour. Amer. Soc. Agron., v. 11, p. 49–67, 1919.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 MAY, 1922 No. 5

THE EFFECT OF FERTILIZERS ON YIELD AND MARKET CONDITION OF CORN.[1]

W. B. ELLETT AND T. K. WOLFE.[2]

In the application of fertilizers to the soil the primary object is usually to increase the yield of the crops. However, in some instances the fertilizers applied noticeably affect the crops in other ways than in increasing yield. These effects are usually classed as secondary; but they very often play an important role in crop production. It has been shown that certain plant nutrients decrease the winter-killing and Hessian fly injury to wheat. In the case of corn some fertilizers hasten maturity, increase the percentage of marketable grain, and the proportion of grain to cob.

The data presented in this paper were secured from a four year rotation experiment, from a continuous cropping experiment with corn, and from a green manuring experiment. Various fertilizers have been applied as shown in the tables. The soil on which the experiments were conducted is a Hagerstown silt loam. The acid phosphate used was the commercial goods guaranteed to contain 16 percent available phosphoric acid. However, analyses were made each year of all commercial fertilizers used.

The rotation experiment was begun in 1909 and consisted of corn, wheat, and clover and grasses two years. Each year all four crops were grown. The materials were applied annually unless otherwise stated. The data secured from this experiment are presented in Table 1.

It is shown in Table 1 that phosphates and manure have increased the yield of grain. In case of commercial fertilizers lacking phos-

[1] Contribution from the Virginia Agricultural Experiment Station, Blacksburg, Va. Received for publication, November 4, 1921.

[2] Chemist and Associate Agronomist, respectively.

TABLE 1.—*The effect of fertilizers on the yield and marketable grain of corn in rotation, for the years 1915 to 1920, inclusive.*

Fertilizer applications per acre.	Results compared in bushels per acre.		Marketable grain.	
	Average yearly yield.	Increase over check.	Average percent.	Increase over check
Acid phosphate, 438 pounds	50.33	13.56	77.60	11.10
Dried blood, 308 pounds Acid phosphate, 438 pounds Muriate of potash [illegible]00 pounds	59.09	22.32	83.19	16.69
Acid phosphate, 4[illegible] pounds Muriate of potash, [illegible] pounds	52.65	15.88	82.30	15.80
Muriate of potash, [illegible]00 pounds	38.39	1.62	70.52	4.02
Dried blood, 308 pounds Muriate of potash, 100 pounds	40.32	3.55	65.75	—.75
Dried blood, 308 pounds Acid phosphate, 438 pounds	44.17	7.40	71.24	4.74
Dried blood, 308 pounds	32.80	—3.97	61.16	5.34
Manure, 16 tons before corn	63.00	26.23	80.18	13.68
Manure, 4 tons annually	65.49	28.72	83.43	16.93
Manure, 16 tons before corn Acid phosphate, 438 pounds annually	70.91	34.14	83.36	16.86
Floats, 218 pounds	40.46	3.69	68.08	1.58
Check	36.77	......	66.50	......

phoric acid, the increase in yield has been small and there was actually a decrease when dried blood has been used alone. It can be seen also that acid phosphate has given a larger increase than has floats or ground phosphate rock. It seems that organic matter and phosphates are the chief limiting factors of production under the conditions of these experiments. There were two checks used in the test and the difference in yield was 4.43 ± 6.18 bushels.

In case of marketable grain, as well as with yield, the materials which has given the most marked results are soluble phosphates and stable manure. The difference in the checks in regard to the marketability of grain was 10.13 ± 5.48 percent.

The value of soluble phosphates in hastening the maturity of corn has been shown by Brooks (1).[3] Hall (4), quoting from the work of Sir John Lawes, states that phosphoric acid stimulated root growth and the propensity of plants to tiller. Grantham (3) emphasizes the value of phosphoric acid in increasing the tendency of wheat to tiller and the effect of tillering on the yield of the plant. Wolfe (5) has found that phosphates, lime and stable manure increase not only the yield but the percentages of marketable grain, grain to cob, and matured ears of corn when the crop was grown in rotation and under continuous cropping conditions. It seems that the right proportion of nitrogen, phosphorous and potassium is more important

[3] Reference by numbers is to "Literature cited." p. 158.

in regard to maturity and growth than is any single element. Ellett and Wolfe (2) found acid phosphate and stable manure to be effective in increasing yield of wheat by lessening the injury from winter-killing and the Hessian fly.

The continuous cropping experimental plots were started in 1908 and have been planted to corn each year since that time. The applications of the different materials were made annually in the spring. The results in regard to yield and percentage of marketable grain are presented in Table 2.

TABLE 2.— *The effect of fertilizers on the yield and marketable grain of corn under continuous cropping, for the years 1915 to 1920, inclusive.*

Treatment.	Results compared in bushels per acre. Average yearly yield.	Increase over check.	Marketable grain. Average percent.	Increase over check.
Acid phosphate, 600 pounds	29.66	16.91	67.93	37.38
Acid phosphate, 200 pounds	27.38	14.63	62.72	32.17
Floats, 99.6 pounds	25.64	12.89	62.81	32.17
Thomas slag, 192 pounds	22.19	9.44	62.26	31.71
Nitrate of soda, 100 pounds; Acid phosphate, 200 pounds	28.87	16.12	62.24	31.69
Acid phosphate, 200 pounds; Sulphate of potash, 50 pounds	23.61	10.86	58.97	28.42
Nitrate of soda, 100 pounds; Sulphate of potash, 50 pounds	14.78	2.03	43.04	12.49
Check	12.75	......	30.55	......
Manure, 10 tons	53.41	31.24	80.83	24.56
Manure, 10 tons; Burnt lime, 1,200 pounds	57.09	34.92	80.17	23.90
Burnt lime, 1,200 pounds	43.04	20.87	70.11	13.84
Nitrate of soda, 100 pounds	21.13	—1.04	56.39	.12
Nitrate of soda, 100 pounds; Acid phosphate, 200 pounds; Sulphate of potash, 50 pounds	41.65	19.48	65.14	8.87
Check	22.17	......	56.27	......

The results secured from the use of 200 pounds of acid phosphate to the acre have been about equal to those secured from the use of 600 pounds of this material. If the data are considered as a whole, it seems that 200 pounds of acid phosphate to the acre is about the proper amount for corn under the conditions of the experiment, from the standpoint of profit. In the continuous cropping experiment, floats or ground phosphate rock, Thomas slag, and acid phosphate gave practically equivalent results when the materials were applied so as to supply amounts of phosphoric acid equal to that in 200 pounds of acid phosphate.

The results of Table 2 indicate that phosphate, lime, and manure are important in increasing the yield and the percentage of marketable

grain in case of corn. When commercial fertilizers have been used without phosphate both the yield and percentage of marketable grain is lower.

If the results secured from the use of the complete fertilizer and from the stable manure are compared, it will be found in the continuous cropping test, that the stable manure has given both higher yield and higher percentage of marketable grain than has the complete fertilizer. The former material supplies annually approximately 120 pounds each of nitrogen and potash and about 60 pounds of phosphoric acid. The complete fertilizer furnishes annually 16 pounds nitrogen, 32 pounds of phosphoric acid, and 25 pounds of potash; manifestly the stable manure supplied much larger quantities of these plant nutrients. Thus, the stable manure and the complete fertilizer results are not strictly comparable. It is difficult to estimate the proportion of the increase that should be attributed to the organic matter and the part to the additional plant nutrients in the stable manure.

In the rotation experiment, the complete fertilizer and stable manure, four tons annually, gave practically the same percentage of marketable grain, but the latter produced the higher yield. In the complete fertilizer, there was supplied 40 pounds of nitrogen, 80 pounds of phosphoric acid, and 50 pounds of potash. The stable manure supplied approximately 48 pounds each of nitrogen and potash and 24 pounds of phosphoric acid. These figures show that the stable manure and complete fertilizer added practically the same quantities of nitrogen and potash, but the former supplied only one third as much phosphoric acid. However, the data in Table 1 show that the average yield of the manured plot surpassed that of the complete fertilizer plot by 6.4 bushels. The percentage of marketable grain produced was approximately the same from the two treatments. Such results would indicate that the difference in yield may be attributed to the effect of the organic matter in the stable manure. It would also appear that applications of acid phosphate as heavy as made in this experiment are not necessary from the standpoint of remunerative returns. When acid phosphate was added to a 16 ton application of manure the yield was increased by 7.91 bushels, as compared with 16 tons of manure alone; while the marketable grain was increased only 3.18 percent. The application of stable manure and acid phosphate gave an increase in yield of 11.82 bushels greater than the complete fertilizer, while the percentage of marketable grain from the two treatments were practically the same. The increase in yield from the 16 tons of

stable manure and acid phosphate, as compared with the complete fertilizer, is about twice that of the four tons of stable manure annually when the latter is compared with the complete fertilizer treatment. However, the amount of phosphoric acid applied in the stable manure and phosphate treatment is about seven times that supplied by the four tons of stable manure annually. Thus, it is evident that the increased yield from the former treatment is not profitable. This is to be expected if the law of diminishing returns is followed.

The effect of green manuring on the yield and percentage of marketable corn is shown in Table 3. This experiment was started in 1917 and includes three one-tenth acre plats. Corn was grown each year on plats to which were applied acid phosphate at the rate of 400 pounds to the acre. On two of the plats a mixture of winter vetch and crimson clover was seeded at the last cultivation of the corn. The third plat was left bare through the winter and serves as a check plat. The crop on one of the plats was cut each year, while the crop on the other crimson clover-vetch plat was turned under. The winters of 1917 and 1920 were very severe and the crops were failures. Hence, there was nothing to be turned under in the following springs. The total amount of crops in the form of field cured hay removed the other two years was 838 pounds. This is equivalent to about 3500 pounds of green material. The data secured are presented in Table 3.

TABLE 3.— *The effect of green manuring on the yield and marketable grain of corn, for the years 1917 to 1920, inclusive.*

	Results compared in bushels per acre.		Marketable grain.	
Treatment.	Average yearly yield.	Increase over check.	Average percent.	Increase over check.
Crimson clover and vetch cut off..	42.67	—.41	83.56	—.14
Crimson clover and vetch turned under..........................	48.74	5.66	86.46	2.76
Check..........................	43.08	......	83.70	......

The results shown in Table 3 indicate that the green manuring crop has had but little effect on the percentage of marketable grain. The effect on yield is more pronounced. It is interesting to observe that from the plats where the crops of vetch and crimson clover have been removed the yield and quality of corn has been maintained. In the rotation experiment, Table 1, it appears that the organic matter of the stable manure increased the yield of grain, but had little effect on the percentage of marketable grain as compared

with complete fertilizers treatment. This apparent effect of organic màtter in the stable manure is substantiated by the results obtained with green manure as shown in Table 3. The green manuring crop has returned to the soil no plant nutrients, other than nitrogen, except those secured from the soil. Thus, a larger amount of the increase in yield from a green-manuring crop can be directly attributed to the effect of organic matter than when stable manure is used. In the latter material the plant nutrients introduce complicating factors.

The results indicate strikingly that the materials which increase the yield of corn are also those which increase the percentage of marketable grain. These materials are phosphates and stable manure. These same materials have previously (2) been found to increase the yield of wheat and to reduce the injury from winterkilling and the Hessian fly. The soils of Virginia seem in many instances, to be markedly poor in phosphorus and organic matter as indicated by the increase in production of crops when these materials are applied.

Thus, it seems that the materials needed to increase yield are also the ones which will improve the quality of the corn crop.

In conclusion, the results of these experiments seem to indicate, under the conditions which prevailed, that phosphates and stable manure are the most valuable materials used for increasing the yield and quality of the corn crop.

Organic matter, in the form of green manure as well as in the form of stable manure, has been valuable in increasing yield.

LITERATURE CITED.

1. Brooks, Wm. P. Phosphates in Massachusetts agriculture; importance, selection and use. Mass. Agr. Expt. Sta. Bul. 162, 1915.
2. Ellett, W. B., and Wolfe, T. K. The relation of fertilizers to Hessian fly injury and winterkilling of wheat. *In* Jour. Amer. Soc. Agron., v. 13, no. 1, p. 12–14, 1921.
3. Grantham, A. E. The tillering of winter wheat. Del. Agr. Expt. Sta. Bul. 117, 1917.
4. Hall, A. D. Fertilizers and manures, p. 139, E. P. Dutton and Co., New York, 1910.
5. Wolfe, T. K. Comparative value of phosphate carriers. Commercial Fertilizer, p. 43–47, Walter W. Brown, Atlanta, 1919.

THE NITROGEN INVENTORY AS AFFECTED BY LIVESTOCK VS. GRAIN FARMING.[1]

C. G. WILLIAMS.[2]

In 1910 the Ohio Station began an experiment of comparing livestock with grain farming on the silt loam soil of Wooster, Ohio. The rotation followed is corn, soybeans, wheat and clover. In the livestock system, all the crops grown except wheat are either fed to livestock, or passed into the manure as bedding, and the manure made from the four crops is applied to the succeeding corn crop.

In the grain farming the corn, soybeans and wheat are removed and sold; the stover and straw are left upon, or returned to, the land; and the clover is not harvested but allowed to stand until plowed under the following spring. No livestock is fed in the grain farming system.

Each tract receives two tons of ground limestone and 700 pounds of 16 per cent acid phosphate per acre, per rotation.

THE CROP YIELDS.

It will perhaps be of interest to note the average yield of crops under the two systems.

Eleven crops of corn have been harvested, with the following average yields: In the livestock system 67.90 bushels per acre: in the grain farming 61.18 bushels per acre; a gain of 6.72 bushels in favor of the livestock farming. The average yield of stover in the livestock system has been 3,100 pounds per acre. The stover has not been harvested in the grain farming but may be estimated at 2,790 pounds.

The 10-year average yield of soybeans has been 21.04 bushels in the livestock, and 18.39 bushels in the grain farming. Of straw, 2,043 pounds in the livestock and 1,802 pounds in the grain farming — a gain of 2.65 bushels of beans and 241 pounds of straw in favor of the livestock farming.

The average yield of wheat has been 34.61 bushels in the livestock and 30.42 bushels in the grain farming. Of straw, 3,158 pounds in livestock and 2,617 pounds in the grain farming — a gain of 4.19 bushels of wheat and 541 pounds of straw in favor of livestock farming.

[1] Paper read at the meeting of the Society held at New Orleans, La., November 7, 1921.

[2] Director, Agricultural Experiment Station, Wooster, Ohio.

The average yield of clover in the livestock farming has been 2.23 tons per acre. As the clover is not harvested in the grain farming, the yield can only be estimated. If it bears the same relation to the livestock yield as in the other crops of the rotation it has yielded 1.95 tons per acre, or a difference of 560 pounds per acre in favor of the livestock farming.

THE NITROGEN INVENTORY.

In view of the good applications of phosphorus and calcium carbonate in each system, it is perhaps fair to presume that the larger yields under the livestock system are due in the main to larger supplies of nitrogen available for crop production.

It may be of interest to compare the nitrogen intake and outgo in the two systems of farming with the actual nitrogen found in the soil as sampled and analyzed in July, 1921, 11 years after the experiment was started.

LIVESTOCK FARMING.

The loss of nitrogen per acre, per rotation in the crops grown in the livestock system is as follows:

Crop	Amount	Lbs. nitrogen
Corn	67.9 bu	66.92
Stover	3,100 lbs.	25.23
Wheat	34.61 bu.	41.01
Straw	3,158 lbs.	16.67
Soybean crop	(⅓)	40.52
Clover crop	(⅓)	65.01
Total		255.36

The gain of nitrogen per acre, per rotation, in the livestock system is as follows:

	Lbs. nitrogen
14.46 tons of manure	217.48
Soybean roots and stubble	12.15
Clover, second growth and residues	97 51
Total	327.14

Net gain per acre, per rotation, 71.78 pounds of nitrogen.

GRAIN FARMING.

Similarly, the loss of nitrogen in the grain farming is as follows:

	Lbs. nitrogen
Corn (grain)	60.30
Wheat (grain)	36.05
Total	96.35

(The soybean residues amount to more than the nitrogen taken from the soil.)

The gain in nitrogen is as follows:

	Lbs. nitrogen
Soybean crop	11.16
Clover crop (2/3)	117.02
Total	128.18

Net gain per acre, per rotation, 31.83 pounds of nitrogen.

On the basis of these figures, some of which are only estimates, the livestock system leads the grain farming by 39.95 pounds of nitrogen per acre, per rotation.

As previously stated, nitrogen determinations were made in July, 1921, of each of the four sections in both systems, 40 borings being made for each sample with the following results:

Pounds of Nitrogen Per Acre (2,000,000 Pounds Soil)

Section.	Crop	Livestock system.	Grain system.
A	Corn	2,140	2,000
B	Clover:	1,900	1,800
C	Wheat (stubble)	2,100	2,000
D	Soybeans	2,220	2,100
Average		2,090	1,975

Gain for livestock, 115 pounds of nitrogen per acre.

There has apparently been an accumulation of 115 pounds of total nitrogen more per acre in the livestock farming than in the grain farming, in addition to an average annual increase in crop production, which would call for 6.4 pounds of nitrogen per acre.

The balance in favor of livestock farming, as determined above, is 39.95 pounds per acre, per rotation, or an average annual balance of 9.99 pounds. If this balance could be accumulated for the 11-year period it would amount to 109.89 pounds, or within 5.11 pounds of the excess found in the soil

In conclusion: comparing the two systems of farming as conducted in the experiment in question, it appears that the livestock system results in slightly larger yields of crops year by year, and in a moderate increase in the nitrogen content of the soil.

AGRICULTURAL AND COMMERCIAL VALUES OF NITROGENOUS PLANT FOODS.[1]

A. W. BLAIR.[2]

By agricultural value, we may understand the value as measured by the increase in crop yields when results secured by different nitrogenous materials are compared with some one material taken as a standard. By commercial value, we would naturally understand the selling price of the different materials on a unit basis. One would suppose on first thought that commercial values would vary directly with the agricultural values. As a matter of fact, the situation may be just the opposite. If a nitrogenous raw material, or fertilizer, is high in price it does not necessarily follow that it will give high agricultural returns when compared with other materials.

It is highly desirable that such a relationship should exist, but there are certain reasons why it has not been so in the past, at least. A nitrogenous material may have a characteristic, or property, which is supposed to give it an advantage, or a disadvantage when compared with some other nitrogenous material.

To cite two examples: there was a time when some farmers believed that chemical salts like nitrate of soda had a stimulating effect which in the end was harmful to the soil. On the other hand, others have been inclined to assign an extra high value to organic nitrogenous materials on account of the organic matter which they supply, and also on the ground that they were believed to have more lasting effects than the soluble salts.

During the past quarter of a century the problem has been widely studied by both European and American investigators. These studies have thrown new light on the problem, and have cleared up a number of disputed points.

Nearly three quarters of a century of work at the Rothamsted experiment station has shown that chemical salts may be used

[1] Paper No. 87 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology; read at the meeting of the Society held at New Orleans, La., November 7, 1921.

[2] Associate Soils Chemist, New Jersey Agricultural Experiment Station, New Brunswick, N. J.

continuously without injury to the soil; it has also been shown that the increased yields thus secured result in increased crop residues which go a long way towards maintaining the supply of organic matter in the soil. It has also been shown by carefully planned experiments which cover a period of 25 to 30 years, that organic nitrogenous fertilizers do not have more lasting qualities, when considered from a broad viewpoint, than the more quickly available mineral materials.

It is the purpose of this paper to present in a brief way some of the results secured at the New Jersey experiment station, which have led to this latter conclusion. Field experiments in which different nitrogenous materials have been compared on one-twentieth-acre plots, have been carried on for 14 years, but since the last four years' results have not been fully tabulated, the results for the first ten years only will be given.

FIELD EXPERIMENTS — COMPARISON OF MINERAL AND ORGANIC SOURCES OF NITROGEN.

Three plots have received annual applications of mineral nitrogenous materials: that is, nitrate of soda, ammonium sulphate and calcium nitrate; while three others have received organic nitrogenous fertilizers, that is, blood, fish and tankage. The materials have been applied in such amounts as to give the same amount of nitrogen to each plot. Lime, phosphoric acid and potash have been applied in liberal amounts.

A five-year rotation consisting of corn, oats (two years), wheat and timothy for the first five years and corn, oats, wheat and timothy (two years) for the second five years has been carried out.

The results for the 10 years are summarized in Table 1.

TABLE 1.—*A comparison of mineral and organic nitrogen in a 5-year field rotation.*

	Average yield of dry matter per acre.				Average yield of nitrogen per acre.	
	1908–1912.		1913–1917.			
Treatment.	Grain.	Straw, hay, etc.	Grain.	Straw, hay, etc.	1908–1912.	1913–1917.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Mineral nitrogen (Ave. plots 9, 10, 11)	1283	3163	848	2734	50.9	35.7
Organic nitrogen (Ave. plots 13, 14, 15)	1215	2519	812	2251	40.3	32.3

From this it will be noted that, in every case, the mineral materials gave larger yields and larger nitrogen returns than the organic

materials. The differences are not great, but certainly they are sufficient to show that the organic materials do not have greater lasting properties than the mineral materials.

In a comparison of nitrate of soda with fish and tankage in growing potatoes on a heavy loam soil, using 1,600 pounds of a 4 (NH_3) — 8 (P_2O_5) — 3 (K_2O) fertilizer per acre, the five-year average yields (all grades) are as follows:

All nitrogen from nitrate	251 bu. per acre
All nitrogen from fish	244 bu. per acre
All nitrogen from tankage	241 bu. per acre

In the same five-year test, when one-half the nitrogen was taken from nitrate of soda and one-half from ammonium sulphate, the average yield was 253.4 bushels per acre, and when half was taken from nitrate and half from either fish or tankage the yield was about 257 bushels per acre.

It will be noted that when nitrogen was obtained from two sources the yields were from two to 16 bushels higher than when a single source was used, but the yields with the best two-source mixture were only six bushels more than the yield with all the nitrogen coming from nitrate of soda, and only about three and one-half bushels more than the yield with the nitrogen coming from sodium nitrate and ammonium sulphate, half and half. But the introduction of two percent of organic nitrogen added very materially to the cost of the fertilizer.

CYLINDER EXPERIMENTS — GREEN MANURE AGAINST STABLE MANURE.

During a period of 13 years, 1907–1919, inclusive, a comparison has been made between nitrogen from stable manure used at the rate of 15 tons per acre once in two years and nitrogen gained through the growing of legumes, these being grown as a green manure crop without interfering with the main rotation.

The work has been carried out in cylinders under natural weather conditions, by using a four-crop rotation consisting of rye, corn, potatoes and oats, the four crops being grown every year, and the work repeated on eight types of soil. Lime, phosphoric acid and potash were added in liberal amounts. Corn was harvested as forage and the other crops grown to maturity.

The average yield of dry matter for the four crops (four cylinders) on the eight types of soil for the 13 years was 749 grams or 187¼ grams per cylinder, for the green manure, and 542 grams or 135½ grams per cylinder for the stable manure. This is an increase for the green manure over the stable manure of 38 percent.

It is impossible to give an [illegible] accounting [illegible] two methods of furnishing nitrogen [illegible] be made. A fair estimate for the cost of the manure for the period covered would be $3.00 per ton. This would make the average annual application (seven and one-half tons per acre) cost about $22.50. It is very difficult to arrive at a figure to represent the average cost of putting in a legume green manure, but it seems safe to say that this would not exceed $6.50 per acre. The green manure method would, therefore, result in a saving of $10.00 to $12.00 per acre over the stable manure after making due allowance for the phosphoric acid and potash in the manure, in addition to the larger yields with the former.

In the meantime, the soil in the green manure cylinders has been kept on a level with, and in some cases on a higher plane as to nitrogen content, than the soil of the stable manure cylinders.

CYLINDER EXPERIMENTS — NITRATE OF SODA COMPARED WITH DRIED BLOOD.

For a period of 20 years, nitrate of soda and dried blood have been compared in cylinder experiments on a loam soil in a five-year rotation of corn, oats (two years), wheat and timothy. Lime, phosphoric acid and potash have been supplied in liberal amounts, so that a deficiency of these should not become a limiting factor. The average yields of dry matter, in grams per cylinder, and the percentage of nitrogen recovered have been as follows:

	Dry matter — grams.		Percentage, nitrogen recovered.
	First 10 years.	Second 10 years.	
Nitrate of soda	237	243	62.4
Dried blood	207	185	38.7

In the case of the nitrate of soda it will be noted that the yield for the second 10-year period is greater than for the first, while with blood the reverse is true. The difference in the amount of nitrogen recovered is greatly in favor of the nitrate of soda.

CYLINDER EXPERIMENTS — NITRATE OF SODA COMPARED WITH DRIED BLOOD IN A 50 % SAND AND LOAM-SOIL MIXTURE.

During a period of nine years, nitrate of soda and dried blood have been compared as sources of nitrogen on a soil mixture, 50 percent of which is coarse white sand. As in the other cases, lime, phosphoric acid and potash have been supplied in liberal amounts. Two crops have been grown each year, barley as the main crop, followed by buckwheat as a residual crop (Japanese millet one year); but the fertilizers were always applied for the barley.

The average yields of dry matter in grams per cylinder and the percentage of nitrogen recovered have been as follows:

	Dry matter grams.	Percentage, of nitrogen recovered.
Nitrate of soda	152.1	58.2
Dried blood	126.8	40.4

Of the applied nitrate nitrogen, 58.2 percent was recovered; and of the blood nitrogen, 40.4 percent; a difference in favor of the nitrate of nearly 18 percent.

These cylinders were open at the bottom and exposed to natural weather conditions so that leaching due to the rainfall was not hindered in any way. Therefore, with the yield of dry matter and the nitrogen recovery both decidedly in favor of the nitrate nitrogen, over a period of nine years and with a soil 50 per cent of which is coarse white sand, there seems little reason for saying that the loss of nitrate nitrogen through leaching is greater than the loss of organic nitrogen from the same cause. If it were so, how could the crop yields be maintained over so long a period of years? It could hardly be an accident that in all these cases and during all these years the nitrate nitrogen gave larger yields than the organic nitrogen. There must be some virtue in the nitrate which the organic material does not possess.

For the present we may pass over the reason for this difference, since here we are concerned primarily with what has actually happened or the relative effect of the two materials.

COMMERCIAL VALUES.

But the difference in yield is not the only question to be considered. Since 1903, nitrogen in the form of organic material has been sold at a higher price per unit than nitrogen in the form of nitrate of soda and sulfate of ammonia. However, it is not necessary to point out here how great the differences in price have been. It is enough that nitrogen in the organic materials has cost the farmer more than nitrate and ammonia nitrogen. At the same time in our experiments it has given no greater returns, and indeed in the majority of cases has given lower returns.

A period of 20 years is certainly long enough to give a fair test of the residual effects of such materials, and it would therefore seem that we are not longer justified in saying that the organic nitrogenous materials have greater "staying" qualities than the soluble forms.

The loss of nitrate nitrogen on accou... siderable, otherwise the recovery would be much higher than these and other experiments have shown it to be (about 62 percent under most favorable conditions), but certainly it is not greater, under average conditions, than the loss from organic materials.

It would appear that the crop's ability to use the readily available nitrate early in its growth, and thus get an early and vigorous start, has much to do with the larger yields where nitrate was used.

In conclusion it may be said that the aim of this paper is not to discourage the use of farm manures or organic nitrogenous materials, but rather to insist that their commercial values be made more in keeping with their agricultural values as shown by long time vegetation tests.

A STUDY OF PRESENT AND FUTURE SUPPLIES OF FERTILIZER NITROGEN.[1]

S. B. HASKELL.[2]

Adequate data showing present consumption of fertilizer nitrogen are not available. The best information lies in the reports made by the different components of the fertilizer industry, during the war, to the fertilizer administrator. At that time these reports were required. It is true that business conditions during the war were so abnormal as to raise a question as to the value of statistics accumulated during that period. The same thing, however, may be said of the three years which have elapsed since the close of the war. Therefore, rightly or wrongly, I have taken the year 1918 as a basis for estimating the consumption of fertilizer nitrogen. In all probability the consumption during the present year is less than that indicated in the following table:

CONSUMPTION OF FERTILIZER NITROGEN, 1918.

Of the various methods of classification which may be used in studying the above table of consumption, one of the most significant is on the basis of origin, whether essentially a by-product in nature or otherwise. Classified in this way 64 percent of the fertilizer nitrogen used in the country in 1918 was a secondary product, 36 percent a primary product. The figures show how far removed is the fertilizer industry today from its original and primary function as a scavenger industry.

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Director, Agricultural Experiment Station, Amherst, Massachusetts.

TABLE 1.— *Estimated consumption of fertilizer ammonia in 1918.*

Product.	Total tonnage.	Estimated use in fertilizers. Percent.	Estimated use in fertilizers. Tonnage.	Nitrogen percent.	Pounds of nitrogen used for fertilizer.	Units of ammonia (1 unit = 16.47 lbs. nitrogen.)
Packing Industry						
Tankage, high-grade	[1] 211,329	[2] 56.9	120,246	[4] 9.0	21,644,280	1,314,164
Tankage, low-grade	[1] 59,604	[2] 89.5	53,346	[4] 5.2	5,547,984	336,854
Dried blood	[1] 35,463	[2] 83.6	29,647	[4] 11.4	6,759,516	410,414
Hair	[1] 8,754	[2] 41.8	3,659	[4] 15.0	1,097,700	66,648
Hoofs and horns	[1] 4,671	[2] 88.3	4,124	[3] 12.5	1,031,000	62,599
Raw bones	[1] 33,644	[2] 82.6	27,790	[1] 2.5	1,389,500	84,366
Dried bones	[1] 21,475	[2] 85.5	18,361	[1] 4.5	1,652,490	100,333
Concentrated tankage	[2] 25,490	[2] 63.4	16,161	[5] 11.2	3,620,064	219,797
Municipal Waste						
Garbage tankage	[2] 34,718	[2] 100.0	34,718	[4] 2.7	1,874,772	[illegible]
Fish Industry						
Dried scrap	[1] 53,028	......	[4] 28,813	[4] 7.4	[6] 4,264,324	[illegible]
Acidulated scrap	....	......	[4] 24,215	[4] 5.0	2,421,500	[illegible]
Vegetable Ammoniates						
Cottonseed meal	[6] 1,616,617	......	[6] 507,186	[4] 6.9	69,991,668	[illegible]
Castor pomace	....	......	[4] 36,481	[4] 5.4	3,939,948	[illegible]
Miscellaneous						
Leather scrap	....	......	[4] 13,892	[4] 10.7	2,972,888	[illegible]
Natural guano	....	......	[4] 52,549	[4] 6.4	6,726,272	[illegible]
Base goods(?)	....	......	[4] 502,132	[4] 2.0	20,085,280	1,219,507
Miscellaneous	....	......	[4] 29,259	[4] 5.0	2,925,900	177,650
Total organic	....	......	1,502,579	....	157,945,086	9,589,878

TABLE I.—(*Continued*)

Inorganic						
Nitrate of soda	....	......	[4] 234,794 [7] 78,265	[4] 15.5	97,048,290	5,802,[illegible]
Sulfate of ammonia	[8] 388,457	......	[4,9] 103,356	[4] 20.0	41,342,400	2,510,[illegible]
Ammonium phosphate	....	......	[4,10] 7,098	[4] 10.7	1,518,972	92,2[illegible]
Cyanamid	....	......	[4,10] 6,099	[4] 12.8	1,561,344	94,799
Total inorganic	....	......	429,612	....	141,471,006	8,589,618
Total, organic and inorganic	....	......	1,932,191	....	299,416,092	18,179,496

References on basis of which estimates are made

[1] Am. Fert. Handbook, 1921, p. 50.
[2] U. S. D. A. Bul. 798, Table VII, p. 8.
[3] Average of maximum and minimum, Am. Fert. Handbook, 1921, Table IV, p. 50.
[4] U. S. D. A. Bul. 798, Table VI, p. 7.
[5] "Compilation of Analyses." Mass. Agr. Expt. Sta.
[6] U. S. D. A. Bul. 798, Table VIII.
[7] Estimated use in direct, unmixed form.
[8] Am. Fert. Handbook, 1921, p. 96.
[9] Does not include that applied in unmixed form.
[10] Below normal — probably of no significance.

A second significant classification has to do with domestic *versus* foreign origin. The only material in the whole list which is now imported in quantity is nitrate of [illegible] r, sulfate of ammonia was likewise imported [illegible] me these importations are practically nil. Cyanamid comes from Canada; but to all intents and purposes this is domestic production. In 1918, 32 percent of our nitrogen was imported, 68 percent produced in America.

Theoretically all of the nitrogen produced in the country, particularly by-product nitrogen, should be used before making importations to complete the available supply. This statement, however, cannot be made in dogmatic form, because nitrate of soda as a source of nitrogen has certain properties not found in other materials. It may be a better carrier under some conditions, or a poorer carrier under other conditions. It is this essential difference between the crop-producing values of the several carriers of nitrogen which makes probable some importations of nitrate, almost without regard to the supplies of domestic nitrogen available for use.

But in order to get a true picture of the conditions of our nitrogen supply, it is necessary to go a step further and discuss the domestic nitrogen in terms of primary and secondary products. 95 percent of the total domestic nitrogen is of by-product nature, with but 5 percent ranking as a primary product. This classification is exceedingly important, since one of the economic functions of the fertilizer industry is to furnish a market for the waste products of a number of other industries. Any governmental policy having to do with the nitrogen supply, which fails to consider this relationship of the fertilizer industry to other industries, is certain to cause difficulties of an economic nature.

A final classification, and this time of agronomic significance, is that of form of nitrogen. Barring fruitless argument as to what constitutes organic or mineral nitrogen, it will be seen that approximately one-half of the total supply of fertilizer nitrogen is from organic sources. The remaining half is usually considered to be in inorganic form, despite the fact that cyanamid, chemically, is an organic product. Of this second half, roughly five-eighths is a primary mineral product, nitrate of soda. Sulfate of ammonia is a by-product of manufacture. Ammonium phosphate and cyanamid are primary manufactured products.

It is interesting to compare the 1918 consumption of nitrogen with that of 1913, five years previous. According to the report of the Federal Trade Commission, the consumption in the latter year totaled

16,859,874 units of ammonia. On this basis, the period from '13 to '18 [illegible] increase in cons[illegible] [illegible] percent. In all probability this figure [illegible] have been the case had the 1918 supplies of fertilizer nitrogen been larger. The limitations during that year were in quantity and not in demand.

OUR FUTURE SUPPLIES.

To plot the consumption of fertilizer nitrogen for past periods of record is easy. To calculate the increase in consumption period by period is likewise easy, as is also the labor of carrying out the curve estimating probable consumption in any year in the future. The real need for fertilizer nitrogen, however, is a function of population density and standard of living. The actual utilization of this nitrogen is dependent on the ratio between its cost and prices received by farmers for crops. The fulfillment of any prophecy regarding consumption is so dependent on world-wide conditions as to make such prophecy of doubtful value. The tariff policy of the United States will have a direct effect on the amount used. Should this policy handicap American producers in finding an export market, the total production of farm crops in this country will be less than would otherwise be needed—hence a slowing up in demand for fertilizer nitrogen. The labor policy, taxation policy, transportation conditions,—all of these have influence on a problem which is basically economic. Therefore, in place of estimating the future supply I must content myself with saying a few words on the limitations of each source of supply.

THE BY-PRODUCT PACKING INDUSTRY.

According to a representative of the Armour Fertilizer Company (page 71, Federal Trade Commission Report on the Fertilizer Industry), the amounts of tankages and blood recovered per animal slaughtered in the large abattoirs of the country are as follows:

TABLE 2.— *Pounds of by-products per animal.*

	Tankage	Blood.	Concentrated tankage.
Cattle	12.	7.	6.
Calves	2.4	.75	1.2
Sheep	1.2	.5	.6
Swine	4.8	1.2	2.4

Applying these figures to the last year of record of the commercial slaughter in the United States, we have in sight the production of tankage equivalent to 223,415 tons; of blood, 89,054 tons; and of

concentrated tankage, 111,707 tons; supplying a total of 5,200,000 units of ammonia. As a matter of fact this production will never be attained. The only present-day effective utilization of by-products is in the plants of the large packing houses. Municipal abattoirs seemingly have not been so [illegible] utilization of by-products. There is [illegible] llation of by-product plants for a business relatively as small as that of municipal abattoirs can be profitably made.

As regards importations from the Argentine, I am not prepared to make statement. Data are too few to admit of a safe generalization. As regards the possibilities of increased production in this country, I cannot see how there can be any great increase in the live-stock industry of this country. United States census figures show a marked decline in animal units per unit of population from 1890 to 1920. In the former year this ratio was 93, for 1910 it had decreased to 69, the 1920 figure indicates 65. These figures show that with increasing population, and correspondingly increasing need for fertilizer nitrogen, there will be a relatively decreasing supply of by-product materials of animal origin. Coupled with this is the probability that in response to economic tendencies there will be an increase in utilization of tankage as feeding material. Digester tankage has been defined as "any tankage that has been cooked in a tank with forty pounds live steam pressure; that has been promptly pressed and dried so that the tankage will not become sour; that does not contain hair, hoofs and other foreign material that are not generally accepted as desirable carriers of protein." According to the table presented above, slightly less than half of the high-grade tankage is now in use for feeding purposes, with but a small percentage of the low-grade tankage so used. There will always be fertilizer tankage made in slaughter houses; but the indications are that more and more of this material will be used as animal food. This is in accord with the dictates of sound economy. It means, however, that we must look elsewhere for sources of nitrogen having the properties usually ascribed to animal organic substances.

FISH BY-PRODUCTS.

The conclusion regarding the supply of fish waste as fertilizer material must be much the same as that for animal organic products in the packing houses. There can doubtless be increased conservation of these by-products; but when one remembers that many of the fish caught are dressed at sea, with the waste thrown overboard, and that the cost of recovery in small plants is very much greater than it is in large plants, a question is naturally raised as to whether the

future will see greater supplies than are available at present. The very least that can be said is that in the period from 1912 to 1920, the only period which is available for study, not only was there no increase in the supply of fish by-products but there was [illegible] actual decrea[illegible]. Perhaps this may [illegible] factor which will bring about in[illegible] source of nitrogen is high-priced nitrogen.

VEGETABLE AMMONIATES.

In 1918 cottonseed meal supplied slightly less than one-fourth of the entire supply of fertilizer nitrogen in the United States. The great bulk of this was, of course, used in the South, in the place where it was produced, with relatively small quantities going north to be used as tobacco fertilizer. Fundamentally, every pound of undamaged cottonseed meal which goes into fertilizer is partially wasted. It should be fed. If the campaign, favored by the United States Department of Agriculture and ably supported by the different states of the South, for a more vigorous live-stock industry in the South is successful, it is probable that increasing quantities of cottonseed meal will be consumed as animal feeds year after year in the South. Furthermore the continued development of the dairy industry in the North will likewise cause increased quantities to be consumed directly as feed. The tendency therefore in the future must be towards decreased supplies of this by-product to be used as fertilizer. Other vegetable ammoniates are scarcely a factor in the market, except locally. As far as can be seen, there is no probability of large increase.

MISCELLANEOUS ORGANIC PRODUCTS.

There are four other sources of nitrogen which have more than local importance, at least for purposes of discussion. These include (1) leather waste, wool waste, etc.; (2) garbage tankage; (3) peat; and (4) sewage.

The utilization of leather and wool waste was in years past held back through question of the value of these materials as carriers of nitrogenous plant foods. The use of acid and heat in processing these materials has largely removed this objection to their use. The future, however, holds no promise of any greatly increased supplies.

As far as garbage tankage is concerned, continued development is dependent on the possibility of profitable production of the main product of garbage extraction, namely, grease in its various forms. It is stated that the installation of local reduction plants so equipped as to render possible the final production of garbage tankage must

be confined to cities of not less than 100,000 inhabitants. On this basis, the total maximum supply which may be expected from this source in the cities lying east of the Great Plains will be approximately 1,500,000 tons of garbage annually, from which approximately 200,000 tons of tankage can be produced, supplying a grand total of not more than 675,000 units of ammonia. This maximum, however, will not be attained in the near future, if ever.

Another potential source is peat. Barring the possibility of developing a biological process whereby the nitrogen of peat may be made available as a food for plants, there is no great hope in the present outlook. In the dim and far distant future it may be used as a source of fuel gases, with ammonia as one of the more prominent of the by-products. The only thing which can hasten this development, however, is the coming of high-priced nitrogen. The need of the country today, however, is for low-cost fertilizer nitrogen. For the present, therefore, peat, and likewise sewage, may be dismissed from consideration as significant sources of this important plant food.

Apparently, as far as one can see, the fertilizer industry of tomorrow must depend more largely on inorganic nitrogen than it has in the past. This may necessitate changes in certain of the manufacturing processes in the making of fertilizer, and likewise changes in the field practice in the use of fertilizer. Unless nitrogenous sources develop entirely different from any known today, however, these changes will be forced through sheer inability to obtain sufficient supplies of nitrogen in organic form.

SULFATE OF AMMONIA.

Ammonium sulfate is at present our largest single source of domestic-produced nitrogen. The United States now produces a supply sufficient for home use, together with a rather material margin for export. Thus, in 1920, the production in round numbers was 500,000 tons, containing 12,143,291 units of ammonia, or sufficient to furnish two-thirds of the quantity of fertilizer nitrogen used by the entire country in 1918.

No official data are available showing exports for 1920. From May on, however, 66,714 tons were exported. For the first eight months in the current year, the export was 41,760 tons. Previous to 1919, however, very little was sent out of the country. It is interesting in this connection to note that the present production of sulfate of ammonia is equal to two and one-half times that which was produced before the war. The Muscle Shoals plant No. 2, or " Cyana-

mid Plant", has a rated capacity equal to 40 percent of the by-product coke industry. Later on the question will arise as to whether the country can consume this tremendous supply of a single source of ammonia.

As is well known, the supply of nitrogen in the bituminous coal deposits of the country is very great. As an average about 20 pounds of nitrogen are contained in every ton of bituminous coal mined; but in 1913 only one-fourth of the coal coked was in ovens equipped for by-product manufacture, producing as one among many products, sulfate of ammonia; while in 1920, 60 percent of the coal coked was in by-product ovens.

It is interesting in this connection to note the variation year after year in the production of coal coked in the bee-hive ovens, as compared to the approximately constant production of coke from by-product ovens. The following table shows this variation, and also indicates the relatively enormous increase in the production of sulfate of ammonia from by-product coke ovens. From 1910 to 1915 the increase was rather slow absolutely, although as large relatively as it is from 1915 to 1920. Should the production of ammonium sulfate continue to increase in the geometrical progression illustrated in the two half decades shown in the table, the amount would soon be so great as to stagger the imagination. Naturally nothing of this sort can be expected.

TABLE 3.—*Bituminous coal coked, 1910–1920.*[3]

Year	By-product coke		Bee-hive coke		Total
	Quantity (short tons)	Percentage of total	Quantity (short tons)	Percentage of total	
1910	7,138,734	17.12	34,570,076	82.88	41,708,810
1911	7,847,845	22.07	27,703,644	77.93	35,551,489
1912	11,115,164	25.27	32,868,435	74.73	43,983,599
1913	12,714,700	27.46	33,584,830	72.54	46,299,530
1914	11,219,943	32.47	23,335,971	67.53	34,555,914
1915	14,072,895	33.8	27,508,255	66.2	41,581,150
1916	19,069,361	35.0	35,464,224	65.0	54,533,585
1917	22,439,280	40.4	33,167,548	59.6	55,606,828
1918	25,997,580	46.0	30,480,792	54.0	56,478,372
1919	25,143,542	56.1	19,650,000	43.9	44,793,542
1920	30,908,000	60.0	20,980,000	40.0	51,880,000

The great bulk of the sulfate of ammonia produced in this country comes from the by-product coke oven. Few of our municipal gas plants produce ammonia as a by-product. This contrasts rather

[3] Years 1910–1914: From "Mineral Resources of the United States," 1914.
Years 1915–1920: From "Mineral Resources of the United States in 1920" (Preliminary Summary).

strongly with German and English practice, in which such production is customary. There is a possibility that the limit of erection of by-product ovens has already been reached. Ovens of this kind must be operated continuously day and night, and cannot be shut down as may be dictated by fluctuations of the steel industry. On the other hand, the time may come when coke as a smokeless fuel must take the place now held by anthracite. Certainly, the waning supplies of anthracite coal give grounds for this supposition. Despite the enormous increase in the amount of coal now being coked in by-product ovens, the waste inherent in the consumption of bituminous coal in other ways is enormous. The end of possible production of ammonium sulfate has not nearly been reached.

ATMOSPHERIC NITROGEN.

Atmospheric nitrogen, as fixed in electro-chemical ways, is a primary product made possible through the commercial sale of power. Its cost depends first on the capital invested in the plant and machinery, and secondly on capitalization of power privileges, patent rights and the like. Up to date there is but one plant in the country furnishing any quantity of fixed nitrogen per year, this being that of the American Cyanamid Company with its plant at the Canadian side of the Niagara Falls. Its rated capacity is 72,000 tons annually, of which between 40,000 and 45,000 tons go into fertilizer, with the balance entering the manufacture of such products as cyanide, ammophos, etc. Running at full capacity, therefore, the plant of the American Cyanamid Company is now equipped to supply us with one-twenty-fifth of the 1918 consumption of fertilizer nitrogen.

To date cyanamid is the only product of the fixation of atmospheric nitrogen which gives great promise commercially. The basic reason for this lies in economical utilization of power. According to C. G. Gilbert (Smithsonian Institute Special Bulletin, 1916),

> "The arc method of nitrogen fixation requires from 2.75 to 3 horse power years of electric power per ton of nitric acid yield. The cyanamid process, on the other hand, carried through only to the nitric acid stage, has a power cost of approximately one-half horse power year per ton of nitric acid. The labor costs in the two competing methods are practically equal. The raw material cost may be somewhat greater by the cyanamid method, but not enough larger to counterbalance the very great advantage in cost of power under which it operates."

The final product, however, is in a form which may best be utilized through mixing with other materials. Attempts at the direct application of the product have not been satisfactory. There is a question as to how much more of this material can be utilized directly on American farms.

In addition to the plant of the American Cyanamid Company, we have the great plant at Muscle Shoals, of which unit No. 2 is equipped for the manufacture of cyanamid. Should Congress authorize the use of the Muscle Shoals plant No. 2, it is estimated that by 1924 approximately 45,000 tons of nitrogen can be produced, gradually increasing to 55,000 tons by 1934. This would be equivalent to 6,678,810 units of ammonia, or one-third of the 1918 consumption of fertilizer nitrogen.

Whether the Haber process or any method of commercial nitrogen fixation other than the cyanamid process can be economically utilized, is a question which cannot now be answered. Data are too few and too untrustworthy to admit of answer.

NITRATE OF SODA.

The consideration of nitrate of soda has purposely been postponed until the last, on the somewhat erroneous supposition that all domestic-produced by-product materials would be utilized previous to importing a primary mineral product from abroad. That this assumption will not always hold has already been shown. Practically, however, we may look to nitrate of soda to balance any deficit between domestic production and desired consumption. As to the future supplies, no estimate is presented. Surveys have always been incomplete and more or less unreliable. Reports indicate that year after year lower grades of caliche have been mined. This indicates probably increased efficiency in manufacture rather than approaching depletion of the deposits. Along with this change in quality of the crude mineral, however, has come an increasing overhead tax imposed by the Chilean government. It is difficult to measure the absolute amount of this tax, because of the fluctuations, almost daily fluctuations in fact, in exchange. Gilbert estimates it at approximately $11 per long ton. Probably the most that can be said today is that there is no present evidence of serious depletion of nitrate supplies.

THE ECONOMIC ASPECTS OF THE PROBLEM.

The production of fertilizer nitrogen is economic only when the product may be economically used. To find its largest usefulness the product must be offered at a price which will admit of clear recognition of profit. Just so long as the matter of profit is a subject of fruitless argument, will the use of nitrogen tend to be retarded. The extension of the use of this plant food should come through the competition of product for a market rather than through the competition of the market for the product. The one leads to low prices and economical business administration, the other to high prices

with attendant extravagant and wasteful business administration. With conditions as they are today, not modified by government interference in industry, the commodity competes for the market. Secondary, or by-product nitrogen, competes with primary nitrogen, with the balance of the argument seemingly in favor of the former; for, as stated by Washburn,

"A by-product cannot be driven out of the market by competition, nor is the quantity in which it is produced determined by the demand for it. It must be produced without relation to the demand, and it must be sold without any relation to the cost."

SUMMARY.

The most salient aspects of our nitrogen problem are: a probably decreasing supply of organic nitrogen; a present greatly increased supply of by-product inorganic nitrogen with indefinite potentialities for enlargement; a maintenance for an uncertain but probably long period of years of the production of primary mineral nitrogen; and in the future, a possible greatly enlarged supply of primary manufactured nitrogen, produced by transforming power resources into fertilizer ammonia.

From the viewpoint of the economic aspects of the problem, there are three enormous wastes. The first is the waste of the resources of human life, brought about by the annual consumption of countless hours of human labor spent in the fruitless tilling of soils, the product of which is seriously curtailed through lack of nitrogenous plant food. The second is the waste of the kinetic energy of falling water. The third is the waste of the nitrogen resources of our enormous carboniferous deposits through destructive and wasteful utilization of bituminous coal. The resultant of these three negative forces is seen in increased hours of daily labor necessitated on the part of one or more components of our population — for the bread which the nitrogen could produce if applied to the soil must, in the failure of such application, be produced through the lengthening of the hours of daily toil. The basic difficulty in finding a remedy for these wastes is lack of co-ordination between industry, agriculture and commerce. As yet, however, the best intellects and the keenest minds in the country have failed to present a plan whereby this co-ordination may be secured. Meanwhile these wastes continue. Human life lived unproductively can never be relived; once the energy of falling water is dissipated in its tortuous route to the sea, it can never be regained; the loss brought about by the inefficient use of a single ton of bituminous coal can never be made good. The problem is much larger than merely that of securing a supply of fertilizer nitrogen.

NITROGEN IN RELATION TO CROP PRODUCTION IN THE MIDDLE WEST[1]

S. D. CONNER.[2]

Crops use nitrogen in greater quantities than they do any other plant food element. In cultivated soils large amounts of nitrogen are lost in the drainage waters, also considerable quantities escape into the air.

In an investigation at the Indiana Experiment Station (1)[3] in a study of virgin and cropped soils taken from 31 localities in the state, it was found that the cropped soils had one thousand pounds less nitrogen per acre than was contained in the virgin soils which had never been cropped. The sub-soils showed a loss of four hundred pounds of nitrogen per acre. The decrease from 0.18% nitrogen in the virgin to 0.13% in the cropped soil occurred on land which has had some clover and some manure to help maintain the nitrogen supply. The loss of phosphorus and potash was only ten percent.

With soils not originally so high in nitrogen the loss would be less, but with the system of farming followed throughout the Middle West, it is safe to say that the nitrogen supply of the soil is constantly diminishing. Stirring and aerating the soils, as in the cultivation of corn, causes a much more active nitrification and a much greater loss of nitrogen. In unpublished work at this Station by Coble and Chamberlain in 1920, nitrates were determined in the old rotation plots which have been under experimentation since 1889. Tests were made monthly from samples taken on plots in corn, oats and wheat.

TABLE 1.—*Nitrates in soil, corn, oats and wheat. Average from six rotations Purdue Station, 1920.*

(Parts NO_3 per million.)

	May	June	July	Aug.	Sept.	Average
Corn	9	26	56	64	16	34
Oats	5	3	10	8	10	7
Wheat	8	5	11	8	7	8

During August, when the nitrates were at the highest point, the soil in corn averaged sixty-four parts NO_3 per million, while the land in oats and wheat stubble averaged only eight parts per million.

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Associate Chemist in Soils and Crops, Agricultural Experiment Station, Purdue University, La Fayette, Indiana.

[3] Reference by number is to "Literature Cited," p. 182.

At all times the land in corn contained more nitrate nitrogen than that in other crops. The active nitrification of cultivated soil when it is in corn no doubt explains why corn in the mid-west seldom responds to nitrogen fertilizer. It should be born in mind, however, that while corn does not seem to need nitrogen fertilization on these soils, it is the crop that is diminishing the supply of nitrogen the most rapidly.

Plot 4, Set III East, at the Indiana Station, has had wheat grown without fertilizer or manure continuously since 1889. Nitrogen was determined on the soil from this plot from samples taken at the start. Four determinations averaged .285% nitrogen. Samples taken in 1921, thirty-three years later, had only .215% nitrogen. This is a difference of 1,400 pounds nitrogen in the surface, a loss of over 42 pounds nitrogen per acre per year. As the yield has averaged less than 12 bushels per acre, the nitrogen loss has been about one-third more than that actually removed in the crop. This was on soil which always had a crop growing through the winter. Nitrogen losses would probably be much greater on soil in corn or on land which has laid bare in winter.

It has been pointed out by Bear (2) that the farther south a soil is situated, the more nitrogen is liable to be lost from it by leaching, particularly during the winter; and on the other hand, in the more northern climates the increase of soil nitrogen by bacterial processes, is slower.

While the soils of the mid-west may be ideally situated for greatest efficiency in regard to nitrogen supply, there is no question but that greater efforts must be put forth to replenish and conserve nitrogen. More legumes must be grown, more manure and crop residues must be conserved and returned to the land before maximum efficiency is obtained, even for an extensive system of agriculture. Still greater efforts are needed for intensive cropping.

Far too small a proportion of legumes to other crops is grown. In Indiana not more than one acre in ten of farm crops is in legumes. Ohio authorities have estimated about the same proportion. Clover constitutes over nine-tenths of the legumes in the middle west. In some counties along the Illinois line in northwestern Indiana, not one acre in one hundred is in clover or other legumes.

On four Indiana experiment fields, results have been obtained showing the value of a legume in increasing crops in a corn, wheat, clover or timothy rotation. When corn has followed the legume it has averaged 6.5 bushels per acre more than it has where following

the non-legume. The legume in the rotation caused an average increase in the wheat crop of 3.6 bushels per acre.

While phosphates and lime are usually the most profitable soil amendments that are used throughout the middle west, it should be remembered that much of the value of either phosphates or lime is obtained through the beneficial effect on clover. Without legumes and manure, liming and mineral fertilizers would lead to land ruin. For this reason, it may be said that nitrogen is the most important of all plant food elements.

It has been pointed out by many writers that for legumes to benefit the land most, they must be returned to the soil, either as a crop residue or in farm manures. A notable example of the mismanagement of a legume crop may be seen in northern Indiana, where cowpeas have been extensively grown on sandy soils. It has been found that cowpeas grew luxuriantly on these light soils. The cowpeas were cultivated in rows and harvested by pulling, the whole plant being removed from the field. Under such a system, the limited supply of organic matter and nitrogen was rapidly exhausted and the soil being left bare in the winter, many fields were ruined by the sand blowing away. It is necessary in growing cowpeas on such soils to return some organic matter and to seed to rye or similar crops to hold the soil and the nitrogen during the winter.

When a farmer has utilized legumes and farm manures to best advantage, available nitrogen may sometimes still be too low. In such cases, on some crops, it is profitable to use commercial nitrogen in the fertilizer. As a result of experiments on the North Vernon experiment field, 1913–1920, one dollar's worth of nitrogen in the wheat fertilizer on land receiving lime, manure, acid phosphate and potash, produced crop increases worth five dollars per acre per three year rotation of corn, wheat and clover. On the Worthington field, nitrogen produced only 71 cents profit under similar conditions, the manure and legumes evidently being sufficient to keep up the nitrogen supply.

SUMMARY.

Except on those soils which still have a large portion of unexhausted nitrogen left, the nitrogen problem is the most important soil fertility problem before the corn belt farmer.

Average Indiana soils have lost approximately twenty pounds of nitrogen per acre per year for the last half century and this loss is continuing. Some soils have lost over 40 pounds per acre per year and the time has arrived when the lack of nitrogen is seriously reducing yields.

Legumes and manure are needed in a much larger degree. Less than one acre in ten is in legumes in the Middle West. The proportion of legumes to other crops should be increased two or three times for best results.

On lands which have been exhaustively cropped some nitrogen in the fertilizer will be profitable, at least until more legumes are grown and crop residues and manure conserved and returned to the land.

Much of the profit in the use of lime, phosphate and potash is in the beneficial effect on legumes, thus indirectly these materials act as nitrogenous fertilizers.

LITERATURE CITED.

1. CONNER, S. D. The chemical composition of virgin and cropped Indiana soils. *In* Proc. Ind. Acad. Sci., 1914, 359-363.
2. BEAR, F. E. Adapting fertilizers to soils, farms, crops and climate. *In* Amer. Fertilizer, 52: 72h-72j. 1920.

THE POTASSIUM-NITROGEN RATIO OF RED CLOVER AS INFLUENCED BY POTASSIC FERTILIZERS.[1]

PAUL EMERSON AND JOHN BARTON.[2]

INTRODUCTION.

The most important question before soil investigators today is the development of a practical method whereby maximum crops may be produced without any overproduction in the soil of any element in an available form beyond the amount which the plant can utilize. Any procedure leading to such an overproduction would of course lead to losses. If too much attention is paid to solving the nitrogen problem, for instance, and in order to make the proper amount of nitrogen available to give the best growth, the forces that make potassium available are overstimulated (and results recently secured with red clover indicate this to be the case) then methods for the study of the fertility of soils which involve a consideration of the potassium problem and perhaps others, are certainly necessary. It appears that the question of raising maximum crops without any overproduction in an available form and consequent loss of the soil elements is of greater importance in the conservation of fertility than the question of the influence of any one element if all others concerned are disregarded.

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Assistant Professor of Soils and Assistant in Soils, respectively, Iowa State College, Ames, Iowa.

Investigators have long recognized the fact that at least ten elements are essential for plant growth, four of these, namely nitrogen, phosphorus, potassium and sulfur may rightly be called "critical elements." Very little is known regarding the actual role played by phosphorus, potassium, sulfur and their compounds in plant nutrition and possibly less about potassium than any of the others. This may be due first, to the abundant distribution of potassium in nature and second, to the difficulties encountered in making accurate determinations. Practically nothing is known of the influence which this element may have on the assimilation of other elements by plants and *vice versa*. It is known that the nitrogen content, particularly of legumes, may vary widely. On the other hand, it is usually assumed that the phosphorus, sulfur and potassium content of plants are in more or less constant proportions. (In this paper the discussion will be confined strictly to potassium.) If an analysis shows that the plant contains a larger percentage of potassium than certain arbitrary standards, the fact is simply stated without further investigation. But even these standards may vary widely. The accompanying table shows the variability of nitrogen and potassium, as reported in three standard textbooks, and indicates that the potassium content of red clover may vary as widely as the nitrogen content.

TABLE 1.—*Nitrogen and potassium content of red clover.*
(Recalculated in terms of percent.)

Reported by	Nitrogen	Potassium
Van Slyke	2.1	1.65
Henry	1.97	1.87
Hopkins	1.5	2.00
Hopkins (Agdel Field, Rothamsted)	2.65	1.4
Hopkins (by Von Wolff)	3.05	1.13

It appears, therefore, that the potassium content of plants should receive the same consideration as that given to the nitrogen content. This is not because there is a crying need to conserve the former element, but because a proper regard for posterity demands that our crops be produced with the least possible waste. In other words there is a decided need for an accurate "Index of Productivity." Shall we determine it by measuring the effects of various soil manipulations or additions on plant growth; by determining the chemical composition of the plant; by lysimeter experiments; or shall we modify and develop our methods until they are capable of embracing the many and variable factors concerned with plant food production in the soil and use them as trial indices? Surely we cannot recommend any procedure that will supply, for instance, a stimulative

amount of nitrogen, if at the same time [illegible] ...mulation and probable losses of available potassium. The well known phenomena of the action of certain salts on plants may be used as an illustration of a possible overstimulation without injurious effects on the plant. It is known (16-page 14),[3]

> "that single salts of potassium, magnesium, sodium or calcium in certain concentrations are toxic to plants, while mixtures of the same salts in the same concentrations are not. Thus, solutions of sodium chloride, magnesium sulfate, potassium chloride, and calcium chloride which, when used singly, killed plants whose roots were immersed in them for only a few minutes, formed, when mixed together, a nutrient solution in which the same plants grew normally."

An overstimulation, or an over-production of soluble potassium compounds in the soil, would not, therefore, in a normal soil, produce any injurious effect on plant growth but would, on the other hand make possible a loss of potassium by leaching.

THE ACTION OF POTASSIUM IN PLANT GROWTH.

According to Thatcher (16), the process of the photosynthesis of starch, or the changes necessary to its translocation, are so dependent upon the presence of potassium in the cell sap that the whole process stops at once if an insufficient supply is present. The presence of an ample potassium supply is necessary for vigorous growth of plants, while the absence prevents the possibility of the development of the carbohydrates necessary for vigorous growth. It has been demonstrated, however, (10) (12) that once in the cell the potassium is not immobile like iron, but is mobile like nitrogen and may translocate from old to new leaves or from old leaves and stems to the fruiting parts.

Hopkins and Aumer (7) removed all the soluble potassium from a soil and determined the power of decaying organic matter to liberate potassium from the "insoluble residue." They found that clover grown on this material contained about one-third as much potassium per gram as that produced on a normal soil, indicating that

> "the actual requirement for potassium by clover may be much less than has been estimated from the composition of hay grown on ordinary soils."

They state that

> "much of the potassium commonly found in crops may not be required but merely tolerated, being taken up by the growing plant because of the abundance in the soil."

Hall (6) likewise found an increase in the potassium content of clover; but takes a decidedly different viewpoint from Hopkins and Aumer as to the reason for such a condition. He says

> "whatever may be the explanation, it is found in practice that the growth, etc., is very much promoted by a free supply of potash, and this is manifest upon sand and gravelly soils usually poor in potash."

[3] Reference by number is to "Literature Cited," p. 192.

POTASSIUM VARIABILITY IN PLANTS AS AFFECTED BY ADDITIONS.

While the literature regarding the potassium content of plants is somewhat limited, indications have been secured showing that most of the common crops are able to absorb larger quantities than are apparently necessary for normal growth. Fraps (5) found that corn, sorghum, kafir corn and mustard plants may take up an excess of potash according to the amount available in the soil, the percentage taken up decreasing as the amount of available potash decreases. Curry and Smith (3) found that clover from plots treated with potash contained an average of 0.25 percent more potash than clover from untreated plots. Frear and Erb (4) found a wide variation in the total potash content of corn, oats, wheat and hay crops. They found that on the average for a rotation, the crops harvested from the land that had been fertilized with potash carried off in a given weight of harvested material 40 percent more potash than a like weight harvested from unfertilized land.

It is a well-known fact that the addition of large amounts of soluble potassium salts are toxic to plant growth, but that amounts commonly added in agricultural practices are stimulative in most soils. Smith (15) found that additions of KCl, and K_2SO_4 in amounts up to 500 pounds per acre stimulated plant growth; but that larger amounts retarded growth. True and Geise (17), in growing red clover in quartz sand to which was added Shives' (13) R_5C_2 culture solution as a base modified by additions of KNO_3, KH_2PO_4, KCl and K_2SO_4, applied at the rates of 88.6 pounds and 433.2 pounds per acre, found that KNO_3 gave the greatest dry weight of tops. KH_2PO_4 was second in efficiency, while KCl and K_2SO_4 were less efficient than either of the other two, but produced approximately the same weights. Unfortunately, the plants were not analyzed in any of these experiments. Skinner and Reed (14) point out that clover is a heavy feeder of potash both in aqueous solution and in soil. They indicate that a higher proportion of potassium than of either nitrogen or phosphorus is used in the metabolic processes of the plant. Special attention is called to the fact "that the fertilizer requirement of any particular soil will upset this ratio."

No experimental data have been obtained on the feeding value of a high-potassium hay. Mr. J. M. Evvard, of the Iowa Agricultural Experiment Station informs us, however, that results recently secured with feeding pregnant ewes with potassium carbonate indicate very clearly the need of this element. If this can be supplied in the form of hay, many difficulties will be overcome. At the present time, a cooperative experiment is being planned whereby the feeding and

nutritional value of red clover hay containing varying amounts of protein and potassium will be compared.

It appears from the foregoing st[illegible] must have an important function to perform [illegible]s it is a mobile element, like nitrogen, capable of being translocated to different parts of the plant it seems that its presence must be necessary. Before studies can be made as to the proper amount to be supplied, it becomes essential to know the possible variations in percentage content of potassium in plants and the causes of these variations. In order to determine the effect of applications of common potassic fertilizers upon the potassium-nitrogen ratio of red clover the following series of studies have been completed.

PLAN AND METHODS OF EXPERIMENT.

In the following experiments, the plan was to compare the effects of potassium chloride, potassium sulfate and kainit (12 percent K_2O), added in practical amounts to a uniform soil type, upon the potassium and nitrogen content of red clover. The applications were supplemented by additions of manure, acid phosphate, and a combination of both. C. P. potassium chloride and potassium sulfate were added at the rate of 100 pounds per acre, while the kainit was added at the rate of 400 pounds per acre. Manure was applied at the rate of 10 tons and acid phosphate at the rate of 200 pounds per acre.

The soil used was a Miami silt loam taken from a field that had been previously cropped with potatoes. The length of time that this field has been under cultivation is not known; but is approximately sixty years. Accurate records of the cropping systems followed on this field could not be secured further back than 1917. No fertilizers had been applied between 1917 and the date of sampling and previous applications are extremely improbable. It is believed that an application of manure was made sometime previous to 1917. The cropping of the field for the past five years was as follows: 1916 (possibly) corn; 1917 oats and clover; 1918 clover; 1919 clover; 1920 potatoes. The soil was taken from the field in the late fall of 1920, partially dried, sieved and thoroughly mixed. An analysis of this soil showed that it contained an average of 16,600 pounds total potassium, and 23 pounds water-soluble potassium per acre.

This soil showed a lime requirement by the Truog method, of 2½ tons per acre. An application equivalent to two tons per acre in excess, or a total amount equivalent to 4½ tons calcium carbonate per acre, was made to the entire amount of soil used throughout the experiment. It may be noted here that it is generally stated in agri-

cultural treatises that the application of lime to a soil liberates potash from the soil minerals. That this assumption [illegible] by the lysimeter experiments of Lyon and [illegible] (9) and the extensive review of the subject by Plummer (11). In fact, lime applications may decrease the solubility of soil potassium, as indicated by Brown and MacIntire (2) and more recently by Briggs and Breazeale (1).

In this experiment thirty-two one gallon glazed earthenware pots were used, each being filled with the equivalent of 9 pounds of air dry soil, with the various fertilizers added on the dry weight basis. Moisture content was adjusted to the optimum 22 percent, additions, (by weight), being made three times each week in order to keep it constant. The arrangement of the pots and their duplicate treatments were as follows:

Pot	Treatment
1—2	Nothing — check.
	Series I.
3—4	Lime, 4½ tons calcium carbonate.
5—6	Lime, plus 100 pounds KCl.
7—8	Lime, plus 100 pounds K_2SO_4.
9—10	Lime, plus 400 pounds Kainit.
	Series II.
11—18	Same arrangement as Series I with the addition of 10 tons manure.
	Series III.
19—26	Same arrangement as Series I with the addition of 200 pounds acid phosphate.
	Series IV.
27—28	Lime, manure, acid phosphate, and KCl applied as above.
29—30	Lime, manure, acid phosphate, and K_2SO_4 applied as above.
31—32	Lime, manure, acid phosphate, and kainit applied as above.

The pots were seeded October 18, 1920, with red clover. When the seedlings were about two inches high they were thinned to seven plants per pot, spaced as nearly equally apart as possible. While the plants were growing, the position of the pots was shifted from time to time, to insure similar growing conditions.

While no attempt was made to inoculate the clover in these pots, an examination of the roots at the close of the experiment proved that all were well supplied with vigorous-appearing nodules.

The crop was harvested April 6, 1921 and dried for two days at 85° C. The dried plants were analyzed for total nitrogen and potassium by the regular official methods. The results of these analyses and the ratio existing between the potassium and nitrogen are shown in Table 2.

TABLE 2.— *Total nitrogen and potassium content of red clover from soils variously treated, their ratios. Results expressed as milligrams N. & K.*

Pot No.	Dry wt. of crop. mgm.	Total N in crop. mgm.	Average. mgm.	Total N in crop. percent.	Average. Percent.	Total K in crop. mgm.	Average. mgm.	Total K in crop. percent.	Average. percent.	Ratio K–N.
1	10.7	299.8	....	2.79	....	55.4	....	0.51	....	....
2	13.0	346.1	322.9	2.66	2.72	72.3	63.8	0.55	0.53	1–5.0
			SERIES I.— *Potassium salts plus lime.*							
3	14.5	438.7	....	3.02	....	73.9	....	0.51	....	....
4	11.3	322.9	380.8	2.86	2.94	60.7	67.3	0.53	0.52	–5.6
5	10.5	286.8	....	2.73	....	77.1	....	0.73	....	....
6	12.5	369.5	328.1	2.96	2.84	92.2	84.6	0.73	0.73	1–3.8
7	9.5	290.1	....	3.05	....	85.0	....	0.89	....	...
8	10.0	263.4	276.7	2.63	2.84	59.7	67.3	0.59	0.74	4.1
9	12.0	341.3	....	2.84	....	107.7	....	0.90	....	...
10	10.0	301.2	321.2	3.01	2.92	82.5	95.1	0.83	0.87	3.3
			SERIES II.— *Manure plus potassium salts plus lime.*							
11	9.3	281.4	......	3.02	....	77.5	....	0.83	....	...
12	10.8	316.2	298.8	2.93	2.97	90.1	83.8	0.83	0.83	3.5
13	6.7	190.5	....	2.99	....	60.5	....	0.90	....	...
14	11.7	327.8	259.1	2.80	2.89	107.1	83.8	0.91	0.90	–3.0
15	6.7	188.7	....	2.80	....	58.7	....	0.87	....	....
16	12.5	338.0	263.3	2.70	2.75	116.1	87.4	0.93	0.90	1–3.0
17	12.2	370.9	....	3.40	....	137.6	....	1.13	....	....
18	9.7	296.1	333.5	3.05	3.22	103.9	120.7	1.24	1.18	1–2.8

TABLE 2.—(*Continued*)

SERIES III.—*Acid phosphate plus potassium salts plus lime.*										
19	8.2	227.4	....	2.77	....	54.6	....	0.66	....	...
20	10.5	279.5	253.4	2.66	2.71	69.6	62.1	0.66	0.66	[illegible]
21	9.7	272.3	....	2.80	....	80.8	....	0.83	....	.....
22	13.2	379.1	325.7	2.87	2.83	112.9	96.8	0.85	0.84	1–3.4
23	16.5	492.3	....	2.97	....	109.4	....	0.66	....	....
24	15.2	391.8	442.1	2.57	2.77	109.6	109.5	0.72	0.69	1–4.3
25	15.2	425.2	....	2.80	....	169.5	....	1.11	....	....
26	15.5	423.4	424.3	2.73	2.77	146.8	158.1	0.95	1.03	1–2.6
SERIES IV.—*Acid phosphate plus manure plus potassium salts plus lime.*										
27	8.2	246.9	....	3.01	....	98.4	....	1.20	....	..
28	9.5	284.5	265.7	2.99	3.00	101.7	100.1	1.07	1.13	[illegible]
29	9.5	303.4	....	3.19	....	111.7	....	1.17	....	..
30	15.2	449.3	376.3	2.95	3.07	133.5	122.6	0.88	1.02	[illegible]
31	13.0	360.6	....	2.77	....	128.4	....	0.99	....	..
32	8.2	228.9	294.7	2.79	2.78	69.6	99.0	0.85	0.92	[illegible]

DISCUSSION OF RESULTS.

From the results reported in Table 2, it appears that applications of lime produced very little if any, effect, upon potassium absorption by red clover. They had, however, a distinct effect upon the nitrogen content, caused greater growth, and consequently caused the plant to take more potassium from the soil; but the lime stimulated nitrogen assimilation so much in excess of potassium assimilation that it materially widened the K-N ratio. A further illustration of the lack of effect of lime on soil potassium was shown in Series I, in every case where potassium salts had been added. Wherever soluble salts were present the K-N ratio was narrowed in spite of the fact that the total dry weight of the crop from the potassium- and lime-treated pots was less than from those with lime alone.

The effect of manure, Series II, was to narrow the K-N ratio consistently. Manurial applications apparently depressed slightly the total dry weight of crop, as compared with the check, in Series I and Series III, but had a stimulating effect on the amount of potassium taken up. This stimulative effect is apparently not influenced by the addition of pure forms of potassium salts, as KCl, or K_2SO_4, but is markedly affected by the addition of the mixed salts in kainit. This absorptive effect is first apparent in the pots treated with manure and lime only. In this case, it narrowed the K-N ratio from 1–5.6 to 1–3.5. The ratio was still further narrowed by the addition of KCl and K_2SO_4. In both of these cases, based on the nitrogen and potassium content of one gram of dry material, there was apparently a slight depression of the nitrogen content and a marked stimulation of the potassium content. Kainit did not depress the nitrogen content, but increased the potassium content of the plants to a point where almost one-half the total potassium added was taken up by the plant.

The results in Series III were surprising in that the greatest dry weight of plants in the entire experiment was found here. The plants in the pots treated with acid phosphate and lime only did not show any increase in weight over the average of the entire series, but their K-N relationship shows that phosphorus has the ability to narrow the ratio and offset the widening effect of lime. Apparently potassium sulfate and acid phosphate applied at the rate of 100 and 200 pounds per acre respectively form the most ideal combination for plant growth in this particular type of soil, as evidenced by the crop produced. Potassium sulphate, however, did not narrow the ratio as much as acid phosphate alone possibly because of an increased stimulation of nitrogen absorption. The plants in the acid

phosphate- and kainit-treated pots took up more potassium than those which received any other treatments in this series. The clover in these pots not only took up an amount of potassium equivalent to the entire amount added but also a portion of the soils supply. The K-N ratio was significantly narrowed, without decreasing the rate of plant growth or producing any apparent injurious effect. This appears to be an excellent illustration of a possible effect of over-stimulation. Had these soils been subject to leaching, as they would be under field conditions, the probability of loss is apparent. Many lysimeter experiments have shown that from five to two hundred and eighty pounds of potash may be lost per acre per year by this means. The amount so lost varies according to kind and type of soil and the treatment applied.

As no check pots were included in Series IV, no attempt will be made to explain the results obtained. Potassium chloride produced the narrowest K-N ratio of the series and the poorest growth. The action of K_2SO_4 and kainit was similar to that of the other series.

SUMMARY.

Pot-culture tests of the effects of applications of various forms of fertilizers to a Miami silt loam soil upon the amounts of potassium and nitrogen on red clover plants grown on it, lead to the following conclusions:

The amount of potassium taken up by red clover from a soil varies with the treatment applied to that soil.

The solubility of soil potassium, as indicated by the percent taken up by the plant, is increased by applications of manure, acid phosphate, or combinations of both.

The ability of red clover to take up potassium varies with the kind of compound supplied; from KCl, it is taken up in the smallest amounts; from K_2SO_4, in larger amounts; while the potassium in kainit, under some conditions, may be entirely taken up. As a rule, the effect of kainit on the amount taken up by the plant is more beneficial than either KCl or K_2SO_4.

Applications of lime in the form of calcium carbonate to an acid soil apparently has no effect on the solubility of native soil potassium, but may possibly overstimulate nitrate production.

The K-N ratio is widened slightly by applications of lime; but narrowed by applications of manure, or acid phosphate or both, in the presence of lime.

The writers desire to express their thanks to Dr. P. E. Brown, Acting Head of the Department, for his helpful criticism throughout the work and the preparation of the manuscript.

LITERATURE CITED.

1. Briggs, L. J. and Breazeale, J. F. Availability of potash in certain orthoclase-bearing soils as affected by lime or gypsum. *In* Jour. Agr. Res., 8: 21–28. 1917.
2. Brown, B. E. and MacIntire, W. H. The relation of certain water-soluble soil constituents in plats 16–24. Ann. Rept. Pa. State Col., 1910–1911. 105.
3. Curry, B. E. and Smith, T. O. Granitic soil potassium and its relation to the production of hay. N. H. Agr. Expt. Sta. Bul. 170. 1914.
4. Frear, Wm. and Erb, E. S. Condition of fertilizer potash residue in Hagerstown silty loam soil. *In* Jour. Agr. Res., 15: 59–81. 1918.
5. Fraps, G. S. The active potash of the soil and its relation to pot experiments. Texas Agr. Expt. Sta. Bul. 145. 1912.

   ——————— The effect of additions on the availability of soil potash and the preparation of sugar humis. Texas Agr. Expt. Sta. Bul. 190. 1916.
6. Hall, A. D. Fertilizers and manures. Dutton & Co., 1915. p. 171.
7. Hopkins, C. G. and Aumer, J. P. Potassium from the soil. Ill. Agr. Expt. Sta. Bul. 182. 1915.
8. Lyon, T. L. and Bizzle, J. A. Calcium, magnesium, potassium and sodium in the drainage water from limed and unlimed soil. *In* Jour. Amer. Soc. Agron., 8: 81–87. 1916.
9. MacIntire, W. H. The liberation of native soil potassium induced by different calcic and magnesic materials, as measured by lysimeter leachings. Soil Sci., 8: 337–394. 1919.
10. Pfeffer, W. F. P. The physiology of plants . . . Trans. by A. J. Ewart. Vol. 1, ed. 2, Oxford, 1900. p. 585–586.
11. Plummer, J. K. The effect of liming on the availability of soil potassium, phosphorus and sulfur. Jour. Amer. Soc. Agron., 13: 162–171. 1921.
12. Schimper, A. F. W. Zur Frage der assimilation der mineral-salze durch die Grüne Pflanze. *In* Flora Jahrg. 73 (n. R. Jahrg. 48). 207–261. 1890.
13. Shive, J. W. A three-salt nutrient solution for plants. Amer. Jour. Bot., 2: 157–160. 1915.
14. Skinner, J. J. and Reid, F. R. Nutrient requirement of clover and wheat in solution cultures. Soil Sci., 12: 287–300. 1921.
15. Smith, R. S. Some effects of potassium salts on soils. Cornell (N. Y.) Agr. Expt. Sta. Mem. 35. 1920.
16. Thatcher, R. W. The Chemistry of Plant Life. McGraw-Hill Book Co. 1921.
17. True, R. H. and Geise, F. W. Experiments on the value of green sand as a source of potassium for plant culture. *In* Jour. Agr. Res., 15: 483–493. 1918.

INFLUENCE OF FERTILIZERS ON YIELD AND MATURITY OF SOY BEANS.[1]

By Geo. L. Schuster.[2]

INTRODUCTION.

Experimenters in soil fertility and crop response have observed that all crops do not respond alike to the same fertilizer and that a given fertilizer will not produce the same results on the various soil types with the same crop.

Scovell and Peter (11)[3] observed that for corn, potash is especially needed on the soils of their State and that wheat is greatly benefited by potash also. They also observed that the greatest profit in every instance was where potash was used.

Neale (9), at the Delaware Station observed that the greatest net profit in every instance resulted from the use of muriate of potash alone, the increased crop due to nitrate of soda being in no case sufficient to meet the increased cost of the fertilizer. He also observed that corn yielded most abundantly with nitrate of soda and muriate of potash, and that wheat gave the best return with nitrate of soda and acid phosphate.

Goessman (3), of Massachusetts Station, stated that sulphate of potash and magnesia on leguminous crops gave, in most instances, better results than muriate of potash. Tests with soy beans showed that potash had the greatest effect upon the increase and quality of the crop. In the soil tests with corn, potash was found to be the controlling factor.

Phelps (10), of Connecticut, reported that nitrogen had very little beneficial effect on either the total yield or the feeding value of cow peas or soy beans, but when supplied in the form of manure increased the yield nearly 9 bushels over that of mineral fertilizers.

Williams (12), of North Carolina Station, stated that ordinary applications of commercial fertilizers hastened the maturity of cotton. High nitrogen (N_3-P-K) applications on all types of soil studied generally produced larger percentages of total yield open at the first picking than high potash (N-P-K_3) applications.

Fellers (2), in his work with soy beans in New Jersey, found that applications of from 50 to 400 pounds of muriate of potash per

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Agronomist, Delaware Agricultural Experiment Station, Newark, Delaware.

[3] Reference by number is to "Literature Cited," p. 197.

acre were followed by an average increase of about 10 percent in the yield of total dry matter and seed ... both limed and unlimed plots; while nodule production ... the limed plots but not on the unlimed. The fertilizer treatment which appeared to give the greatest return for the money invested on acid soils comprised from 200 to 300 pounds of acid phosphate together with a ton of lime.

Lipman and Blair (6), reported that soy beans inoculated and furnished with lime and soluble phosphate made a good growth and accumulated a high percentage of nitrogen up to the time the pods were half filled (hay stage) without the aid of readily soluble potash compounds.

Grantham (4 and 5) stated that for the State of Delaware, potash gives the best results of any single element on both corn and soy beans and recommended an application of 250 to 350 pounds per acre of a mixture of 400 pounds of acid phosphate and 100 pounds of muriate of potash on sandy soils for soy beans.

PLAN OF PRESENT INVESTIGATIONS.

The Wilson variety of soy beans was used in the investigations. They were seeded on tenth acre plots. Diagram 1 shows the arrangement of these plots and the treatment applied to each. The soil is that of the Sassafras series of the Piedmont Plateau province. The soy beans are seeded in a rotation with other crops as follows: (1) Corn (cover crop, rye and vetch), (2) soy beans, (3) wheat, (4) timothy and clover.

2. Sodium nitrate 10 lbs.	3. Acid phosphate 25 lbs.	4. Muriate of potash 7.5 lbs.	5. Sodium nitrate 10 lbs. Acid phosphate 25 lbs.	6. No treatment.	7. Acid phosphate 25 lbs. Muriate of potash 7.5 lbs.	8. Sodium nitrate 10 lbs. Muriate of potash 7.5 lbs.	9. Sodium nitrate 10 lbs. Acid phosphate 25 lbs. Muriate of potash 7.5 lbs.	10. Double quantity No. 9.	11. No treatment.	12. Basic slag 22.5 lbs. Muriate of potash 7.5 lbs.	13. Rock phos. 37.5 lbs. Muriate of potash 7.5 lbs.	14. Manure 0.25 ton.	15. Manure 0.5 ton.

DIAGRAM 1.— Showing arrangement of plots and treatments applied. Each plot is 2 rods wide and 8 rods long.

The average yields for the last six years are reported in Table 1, together with an analysis as to the maturity of the crop. The gram

weight of one pint was determined with a one pint [illegible] tester The d[illegible] presented in the tabl[illegible] correlated with the highest test [illegible] mature beans per 100 grams gradually increases as the yield decreases. The percentage of immaturity by weight is also recorded. This was determined by weighing the number of immature beans in 100 grams. It will be noted that there is a marked increase in the quantity of immature beans and a marked decrease in yield from the plots where muriate of potash has been omitted.

Muriate of potash in combination produces better results than where it is used alone. Heavy applications of manure (5 tons) produce the best results as to yield and maturity. Lyon (7) states that the analysis of average manure is approximately 10–2–12. It is evident that it must be either the nitrogen or potash that is producing the results from manure. Nitrogen on other plots is not giving high yields, so it must be fair to conclude that it is the potash of the manure that is producing the results here recorded.

TABLE 1.—*Showing correlation between immaturity and yield of soy beans.*

Plot.	Treatment per acre.	Gram wt. of 1 pint.	No. beans in 100 gr. mature	No. beans in 100 gr. immature.	Percent immature.	Average yield 6 yrs. bu. per acre.
15	Manure, 5 tons...........	400.0	680	0	0	31.6
10	Double quantity No. 9.....	392.5	645	3	0.2	26.6
9	Sodium nitrate, 100 lbs.; Acid phosphate, 250 lbs.; Muriate of potash, 75 lbs.	403.0	678	6	0.8	25.6
14	Manure, 2.5 tons..........	396.0	669	0	0	25.1
12	Basic slag, 225 lbs.; Muriate of potash, 75 lbs.	388.5	602	43	4.4	23.3
7	Acid phosphate, 250 lbs.; Muriate of potash, 75 lbs.	401.0	701	12	1.2	23.1
8	Sodium nitrate, 100 lbs.; Muriate of potash, 75 lbs.	394.5	696	6	0.3	21.6
13	Rock phosphate, 375 lbs.; Muriate of potash, 75 lbs.	388.5	733	39	4.2	21.5
4	Muriate of potash, 75 lbs...	394.5	730	4	.2	16.9
5	Sodium nitrate, 100 lbs...; Acid phosphate, 250 lbs..	395.5	740	96	7.4	15.1
3	Acid phosphate, 250 lbs....	387.5	669	134	12.0	14.6
2	Sodium nitrate, 100 lbs....	389.5	667	103	9.3	14.2
6	No treatment.............	388.0	628	135	12.6	12.9
11	No treatment.............	375.0	621	221	19.6	12.2

FINANCIAL RETURNS.

The item that is always of practical interest is that of monetary returns. In computing the net returns, nitrate of soda was valued at $92.00 a ton; acid phosphate $18.00 a ton; rock phosphate $8.50

a ton; muriate of potash $384.50 a ton; basic slag $16.00 a ton; manure $3.836 a ton; and the soy beans at $2.85 per bushel.

The mineral fertilizer costs, with the exception of basic slag, were taken from wholesale quotations in the Market Report (8) of the Journal of Industrial and [illegible] 25 percent added for freight and commission to the retailer. The cost of basic slag was based on a quotation from the Tennessee Coal and Iron Company, and 25 percent added for the same reason. The manure was valued on the same basis as the mineral fertilizers according to the analysis given by Lyon (7). Thirty-five cents per acre was added for applying the fertilizers.

TABLE 2.—*Showing correlation between financial returns from fertilizers and immaturity of soy beans.*

Plot.	Treatment per acre.	Average yield for 6 yrs. bushel per acre.	Value of seed per acre.	Cost of fertilizers per acre.	Net returns per acre.	Percentage of immaturity.
15	Manure, 5 tons	31.6	$90.06	$19.53	$70.53	0
14	Manure, 2.5 tons	25.1	71.51	9.94	61.57	0
9	Sodium nitrate, 100 lbs. Acid phosphate, 250 lbs. Muriate of potash, 75 lbs.	25.6	72.96	21.62	51.34	.8
12	Basic slag, 225 lbs. Muriate of potash, 75 lbs.	23.3	66.40	16.57	49.83	4.4
7	Acid phosphate, 250 lbs. Muriate of potash, 75 lbs.	23.1	65.83	17.02	48.81	1.2
13	Rock phosphate, 375 lbs. Muriate of potash, 75 lbs.	21.5	61.28	16.36	44.92	4.2
8	Sodium nitrate, 100 lbs. Muriate of potash, 75 lbs.	21.6	61.56	19.37	42.19	0.3
3	Acid phosphate, 250 lbs.	14.6	41.61	2.60	39.01	12.0
6	No treatment	12.9	36.77	0.00	36.77	12.6
5	Sodium nitrate, 100 lbs. Acid phosphate, 250 lbs.	15.1	43.04	7.20	35.84	7.4
2	Sodium nitrate, 100 lbs.	14.2	40.47	4.95	35.52	9.3
11	No treatment	12.2	34.77	0.00	34.77	19.6
4	Muriate of potash, 75 lbs.	16.9	48.17	14.77	33.40	.2
10	Double quantity, No. 9	26.6	75.81	42.89	32.92	.2

The farm price of soy beans was taken from the Yearbook (13) for 1920.

Table 2 presents the net returns and the percentage of immaturity from the plots.

The plots are arranged in the order of the net returns, the greatest net returns coming first. A general statement may be made that all the potash carrying fertilizers yield greater net returns than those not carrying potash. Such a statement will not hold true, however, where potash alone was used. Potash has had greater increases in price in the last six years than any other fertilizer This will, in

part, explain why potash alone does not bring in any greater net returns. With the present lowering of the price of muriate of potash however it may be used more fre[illegible]

From these observations, manure produces [illegible] and produces no immaturity [illegible] on the Sassafras soil types. When manure is not available, an application of 250 pounds of acid phosphate and 75 pounds of muriate of potash per acre is recommended as being the most economical to apply. Sodium nitrate does not produce desirable results as to maturity or yield. Basic slag and rock phosphate are not so readily obtainable.

SUMMARY.

The presence of muriate of potash in fertilizers for soy beans brings the beans to maturity. This is in accord with the observations of Lipman & Blair (6).

Manure applications of 3 to 5 tons per acre give largest yields in which all the beans mature. It is believed the potash of the manure brings this about.

In the absence of manure, acid phosphate, 250 pounds, and muriate of potash, 75 pounds per acre, is recommended.

The above recommendations are based upon the experiments here reported and may be yield the largest net returns.

With lower-priced potash coming on the market, more potash should be used.

Nitrate of soda does not produce desirable results with soy beans, as to maturity, yield or financial returns.

LITERATURE CITED.

2. Fellers, C. R. The effect of inoculation, fertilizer treatment, and certain minerals on the yield, composition and nodule formation of soy beans. *In* Soil Sci. 4: . . ., 1918.
3. Goessmann, C. A. Field experiments. Mass. Agr. Exp. Sta. Rept., 1893: 227–236.
4. Grantham, A. E. Soy beans. Del. Agr. Exp. Sta. Bul. 96, 1912.
5. Grantham, A. E. Annual report of director, Del. Agr. Exp. Sta. Bul. 119: 9, 10. 1918.
6. Lipman, J. G. and Blair, A. W. Vegetation experiments on the availability of phosporus and potassium compounds. N. J. Agr. Exp. Sta. Rept., 1917: 353–368.
7. Lyon, T. L., Fippin, E. O., and Buckman, N. O. Soils, their properties and management. MacMillan Co., 1916. 578–9.
8. Market reports. *In* Jour. Ind. and Eng. Chem., vols. 7–13: 1915–1921.
9. Neale, A. T. Del. Agr. Exp. Sta. Rept., 1892: 31–35.
10. Phelps, C. S. Field experiments with fertilizers. Storrs (Conn.) Agr. Exp. Sta. Rept., 1901: 122–147.
11. Scovell, M. A. and Peter, A. M. Corn experiments. Ky. Agr. Exp. Sta. Bul. 17. 1889.
12. Williams, C. B. Effects of different fertilizing materials upon the maturity of cotton. N. C. Agr. Exp. Sta., Cir. 12. 1914.
13. Yearbook, U. S. Dept. of Agr. 1920: 666.

SOIL TYPES AS A BASIS FOR SOIL INVESTIGATIONS.[1]

[illegible][2]

Until comparatively recently, practically all soil investigations have been planned and carried out with a magnificent disregard of the particular soil conditions; and the results of field experiments, greenhouse tests and laboratory investigations have been quite generally interpreted as applicable to all soils. Thus, while there seems to have been some appreciation of certain differences in soils, physical or chemical, if such difference were extreme, there has been in the past too much tendency to look upon "any soil as soil," using the term soil in a broad, unrestricted sense.

Our knowledge of soils has increased very rapidly during the past few years, however, by reason of many fundamental studies. It has become evident that soils may be classified into rather well defined series and types, being differentiated on certain definite characteristics. There has been, therefore, a growing tendency among soil investigators to consider seriously the significance of the soil type employed in their studies. There seems, indeed, to have developed some appreciation of the fact that the results of soil experiments are not necessarily applicable to any other soil conditions than those involved in the particular work and that all conclusions should be safeguarded from too broad an interpretation by the qualifying phrase "on this particular soil type."

Twelve years ago, in his presidential address before this Society, Dr. Geo. N. Coffey, then of the U. S. Bureau of Soils, called attention in a very clear and forcible way to the importance of the field study of soils, emphasizing the fact that soil differences may account for many of the "contradictory and seemingly inexplicable results obtained by different investigators or even by the same investigator." He asserted also that "the failure to recognize that the results secured upon one type do not necessarily hold true of another, is responsible in some measure for the distrust of farmers of the work of scientific investigators as well as of the unsettled and unsatisfactory condition of the field problem of soil fertility." How true this assertion is will be apparent when we consider how often the results of fertilizer tests from plots on an experiment station farm are used as a basis for general recommendations to farmers and how frequently the farmers

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Professor of Soil Bacteriology, and Chief in Soil Chemistry and Bacteriology in the Experiment Station, Iowa State College, Ames, Iowa.

have failed to secure similar increases [illegible] wonder if a farmer looks askance at station experiments after such an experience? Is it any wonder that investigators in the pure sciences have said that there is no soil science? Is it surprising that theories of permanent soil productivity have been varied, that controversies have raged and that the general public has failed to derive many of the benefits from soil investigations which the time and money expended on them should have insured?

However, a change of viewpoint in soil experiments is being gradually brought about, altho only very slowly and it is becoming a more generally accepted fact that the particular soil conditions are responsible in large part for the character of the results secured. Thus the weight of sentiment, the increasing knowledge of soil types which is being constantly secured, and perhaps I might add, also, the more accurate soil maps which are being produced, are accomplishing the desired result. Soil studies are now coming to be based more and more on the particular soil type and soil conditions and conclusions are being more carefully and conservatively drawn. But while the development of the soil survey work of the U. S. Bureau of Soils has been very extensive and while many more than the 800 soil types which Dr. Coffey mentioned in 1909 have been recognized and differentiated on the basis of fundamental differences, there are still some investigators who apparently fail to grasp fully the vital significance of basing their studies on the soil type; and many who perhaps thru oversight, to take a charitable view of the situation, draw broad general conclusions from narrow specific soil type experiments.

There are, of course, other factors than a lack of appreciation of soil differences which have brought about the publication in some cases of broadly conclusive, misleading statements and perhaps the making of unsatisfactory practical recommendations. The demands of the farmers themselves for definite advice, the attitude of administrative officers, urging the publication of practical results, the desire for publicity, the willingness to take a chance on how the recommendations work out, in order to gain public recognition, have all played a part in causing the "unsettled and unsatisfactory condition of the great problem of soil fertility" which Dr. Coffey referred to and which still exists, unfortunately, to some extent.

But I would not for one minute disparage the wonderful work which has been done in the past in soil experiments. I would not detract from the great practical good which farmers have derived from practising many of the methods of soil treatment which have been recommended. Many of the suggestions which have been made

have proved of inestimable econ[illegible] the improved methods of soil treatment [illegible] generally prevail are certainly sufficient evidence that soil investigations of the past have not been in vain and that the cost of such investigations has been well warranted. Furthermore, many of the fundamental studies along soil lines have brought out conclusions which are of general application. In other words, the results of many experiments are applicable to *all* soil types and there has really developed in the past decade a science of soils, for which no apology is needed.

There is no need to discredit all previous work, in order to call attention to ways in which future work may be improved. Such an extreme attitude not only casts discredit upon the profession as a whole in the eyes of the general agricultural public, but it is unfair to early investigators and it deliberately ignores the many investigations which lie at the very foundation of soil science.

In a recent publication,[3] a study by statistical methods of the results of the Ohio and Pennsylvania soil experiments is made and it is concluded that it is highly probable that "no fertilizer experiment as ordinarily conducted is possessed of sufficient practical value to justify the large expenditure of money, time and energy involved." The statement is made also that "our present knowledge of the enormous variability of all soils and plants renders the data from any given fertilizer plot of value only on that plot no matter how near the experimental one."

While it is true that many fertilizer experiments have been carried out on land which has not been surveyed and on which the soil types have not been determined, practical results of large value have often been secured. Even tho such experiments have been located conveniently and on college land which might be extremely variable and include more than one soil type, the conclusions drawn from them have led to recommendations which have proved of much use to farmers. It is undoubtedly true, of course, that the experiments would be of much greater value if the plots had been laid out on a definite soil type, of typical topography, without local soil variations of any kind and uninfluenced by previous variable methods of cropping and soil treatment. But to discard all fertilizer experiments, as the authors quoted would recommend, is not only unnecessary but would be deplorable. Fortunately, the radical suggestion is not likely to prevail and not even likely to be considered seriously. The unfortunate part about the publication of such statements is that they bring a certain amount of discredit upon all our soil experimental

[3] Lipman and Linhart, Proc. Nat. Acad. Sci., vol. 6, No. 11, p. 684.

work in the minds of other scientists and if [illegible] would affect also the attitude of our constituents, the farmers, toward our recommendations.

But while it is not necessary to discard the results of all soil experiments carried out in the past, and they may serve to establish certain fundamental and practical principles governing soil management, the importance of determining the soil type is being recognized in the establishment of new experiment fields, with the idea of making the results of the greatest practical value as well as technically accurate. Hence, these new fields are very largely free from the objectionable features mentioned above and the results secured will certainly be applicable to the same soil type under the same climatic and seasonal conditions. When the soil type is determined and the plots are carefully laid out there is no question but that farmers operating on the same soil type will profit from the results secured, especially when the conclusions are safeguarded by being drawn only after results have been secured for several years. Furthermore, there is no question but that such results will yield fundamental and extremely valuable information regarding the particular soil type.

The significance of the soil type in field experiments must not be underestimated and the results obtained from any plot tests should be interpreted as applicable *only* to the particular soil type. No question of the value of the experiments can then arise.

The following table (Table I) gives some results secured on various experimental fields in Iowa. It is evident from these that the soil type plays an important part in determining the results secured and that profitable treatments on one type may not be of value on any other type. Large increases in crop growth may occur on one soil and no increase at all on another. It can readily be seen also that certain treatments prove of value, altho indeed of variable value, on all the types, with the same crops. Thus, lime increases the clover yields and manure brings about larger growth of corn and oats. Other treatments, however, give different effects on the same crop on different soils.

In general this table illustrates the point that results obtained with fertilizers on one soil type will not necessarily be applicable to other types, but it shows also how certain treatments may be of value on practically all types. It gives evidence, therefore, that while the older soil experimental fields may yield results of general practical value, the newer fields, laid out on typical soil types, will prove of far greater usefulness in planning systems of permanent agriculture for soils in general, the particular system adapted to one type needing

TABLE I.— *Yields of various crops under different treatment on soil types in Iowa*

Plot No.	Treatment	Marshall silt loam Corn, bu. per acre	Marshall silt loam Oats, bu. per acre	Marshall silt loam Clover, tons per acre	Grundy silt loam Corn, bu. per acre	Grundy silt loam Oats, bu. per acre	Grundy silt loam Clover, tons per acre	Marion silt loam Corn, bu. per acre	Marion silt loam Oats, bu. per acre	Marion silt loam Clover, tons per acre	Carrington silt loam Corn, bu. per acre	Carrington silt loam Oats, bu. per acre	Carrington silt loam Clover, tons per acre
1	Check	60.0	51.0	1.30	70.4	73.2	1.50	49.4	38.2	1.58	46.5	64.6	1.15
2	Manure	68.5	52.3	1.36	74.9	75.1	1.75	61.7	42.5	1.60	51.1	64.6	1.37
3	Manure+lime	68.5	61.8	1.56	82.2	74.8	2.10	65.8	48.8	1.87	63.3	61.9	1.42
4	Manure+lime+rock phosphate	69.3	63.6	2.89	88.6	76.5	2.30	63.7	65.8	1.91	66.1	76.8	1.67
5	Manure+lime+acid phosphate	73.7	60.4	3.40	101.4	85.1	2.75	68.6	73.3	2.60	60.8	74.8	2.00
6	Manure+lime+complete fertilizer	71.5	73.5	2.55	88.4	80.8	2.65	55.0	68.0	2.85	61.0	80.9	2.00

TABLE I.— (*Continued*)

Plot No.	Treatment	Carrington loam Corn, bu. per acre	Carrington loam Oats, bu. per acre	Carrington loam Clover, tons per acre	Muscatine silt loam Corn, bu. per acre	Muscatine silt loam Oats, bu. per acre	Muscatine silt loam Clover, tons per acre	Grundy silty clay loam Corn, bu. per acre	Grundy silty clay loam Oats, bu. per acre	Webster silty clay loam Corn, bu. per acre	Webster silty clay loam Oats, bu. per acre	Clinton silt loam Corn, bu. per acre	Clinton silt loam Oats, bu. per acre	Clyde silt loam Corn, bu. per acre	Clyde silt loam Clover, tons per acre
1	Check	34.8	42.8	0.80	65.5	47.6	2.07	78.5	65.8	58.0	56.7	61.8	38.2	40.5	1.92
2	Manure	39.0	61.0	1.20	68.8	54.7	2.40	91.3	72.1	57.3	64.1	68.3	53.4	41.0	1.98
3	Manure+lime	40.0	64.9	2.10	75.5	59.2	2.65	92.0	74.2	58.1	63.5	70.6	55.2	51.8	2.24
4	Manure+lime+rock phosphate	52.7	65.5	2.05	77.2	64.9	2.69	95.3	74.2	64.2	69.7	73.5	63.7	61.5	2.28
5	Manure+lime+acid phosphate	50.3	72.1	2.50	81.1	62.2	2.75	99.0	72.1	76.5	76.3	70.8	63.7	63.0	2.54
6	Manure+lime+complete fertilizer	59.2	67.2	.....	78.2	57.5	2.91	98.5	78.5	80.0	68.9	73.0	65.8	83.3	2.34

much modification, perhaps, before being suitable for another very dissimilar type.

But it is not only in field experiments that the soil type is of importance. Greenhouse experiments, chemical studies and bacteriological results are quite as much affected by the soil type employed and too often such results are too broadly interpreted.

Table 2 shows some results from greenhouse tests on different soil types. Similar conclusions might be deduced from a study of this table as were reached from a consideration of the table of field experimental results. There can be no question but that all greenhouse tests should be planned on definite soil types if the results are to be of the greatest practical and scientific value.

Chemical studies on soils are also very largely influenced by the soil type. Careful studies are now under way in our laboratories to determine the relation, if any, which exists between the soil type and its chemical composition. It is realized, of course, that the differentiation in soil types cannot be made on the basis of chemical composition, but it seems quite reasonable to believe that the content of the different elements will vary between certain limits in any one type and that these limits will be different for other types. Particularly is this true when nitrogen and organic carbon are considered, two elements which are particularly significant in soil type separations.

The results of this study will be published later and no data will be given here. It is sufficient to say that the evidence so far secured points very definitely to the fact that the results of studies of the chemical composition of soils must be interpreted on the soil type basis to be of the greatest value.

Some results recently secured with legumes on two different soil types show that the nitrogen content of tops and roots may vary widely; how far the ratio may vary and how the effects on the soils from the growth of legumes will depend upon the soil type. These results serve to emphasize the fact that actual methods of soil management to maintain permanent fertility, at least from the nitrogen standpoint, may vary widely on different soil types.

Many other illustrations of the significance of the soil type in chemical studies of soils might be mentioned and reference given to published results, but it does not seem necessary to cite further work here. Several problems are now under way in our laboratories which involve a consideration of the relation of soil types to certain chemical soil conditions. Organic phosphorus in soils is being studied, hydrogen-ion concentration in relation to acidity and to other acidity tests, carbondioxide production in treated and in untreated soils,

TABLE 2.— *Greenhouse experiments with various fertilizer treatments on Iowa soil types.*

Pot No.	Treatment	Muscatine silt loam		Carrington loam		Clinton silt loam		Marion silt loam		Grundy clay loam		Carrington silt loam	
		Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams
1	Check	22.75	35.5	7.27	6.0	8.34	35.5	8.50	8.0	9.05	63.5	12.53	4.5
2	Manure	25.97	33.0	7.50	35.0	8.55	40.0	10.20	17.0	9.47	73.0	14.76	15.5
3	Manure+lime	30.42	45.0	8.75	57.0	9.30	56.0	11.85	12.0	9.48	75.0	14.67	22.5
4	Manure+lime+rock phosphate	28.55	57.5	9.17	58.0	8.49	49.0	11.45	25.0	11.18	76.0	13.93	21.0
5	Manure+lime+acid phosphate	31.42	63.0	7.77	63.5	9.97	63.0	11.10	39.0	10.35	78.5	15.22	28.5
6	Manure+lime+complete fertilizer	29.02	58.5	9.32	56.5	9.27	56.0	12.22	36.0	11.75	84.0	16.75	36.5

TABLE 2.— (*Continued*).

Pot No.	Treatment	Tama silt loam		Grundy silt loam		Webster silty clay loam	
		Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams	Wheat grain in grams	Clover in grams
1	Check	12.00	8.0	13.85	40.0	26.56	29.5
2	Manure	12.65	31.0	15.80	47.0	29.46	36.0
3	Manure+lime	12.86	51.5	16.61	54.0	31.71	44.0
4	Manure+lime+rock phosphate	14.03	57.0	17.70	62.5	28.95	46.0
5	Manure+lime+acid phosphate	12.72	64.5	15.25	62.0	35.80	45.0
6	Manure+lime+complete fertilizer	13.67	59.5	13.27	70.0	31.13	46.0

response to potassium fertilizers and the making of potassium available, the use of sulfur and changes which the element undergoes in the soil, the color of soils in relation to carbon and nitrogen, available phosphorus by various methods, the composition of humus, etc.

Many results of chemical soil studies which have been published have emphasized the applicability of the conclusions drawn to the particular soil type or the fact that the results varied on different soils. Surely in the light of results secured and from a consideration of the variations among soil types, it must be evident that no chemical studies on soils should be undertaken without a fundamental determination of the soil type.

From a bacteriological standpoint it seems almost unnecessary to call attention to the relation of the results secured in bacteriological studies to the soil type employed. Too much data has been published, however, which has been secured on one soil only and yet has been interpreted as broadly applicable to soils in general. When we consider the various factors which influence bacterial development in soils and then remember how these factors vary in different soils, it will be evident that bacteriological results will be influenced to a large extent by the soil type. Many experiments have shown this fact and while it is often difficult if not impossible, to distinguish and disentangle the various factors which are so closely allied, it is worthy of note that the variations in results may very generally be traced back to the soil type, other conditions being the same.

Our own studies of bacteria at different depths in soils, show how the soil type will govern the development of bacteria in the soil, affecting the numbers, the action and the distribution. Studies on bacteria in frozen soils, on occurrence and distribution of molds, on bacterial effects of lime, of manure, of rotations, of fertilizers, have shown how all bacterial and mold activities are influenced to a more or less extent by the soil type. Numerous experiments of others might also be cited which lead to the same conclusion. Other work now under way in our laboratories which involves the soil type, includes studies of bacteria in relation to crop production; the relation of bacteria to the nitrogen problem, to the phosphorus problem, to the potassium problem, to the sulfur problem and to the commercial fertilizer problem. The recognition of the fundamental importance of the soil type in bacteriological work will insure that our progress in knowledge along this line will be much more rapid and the value of the results secured will be much enhanced.

The question may arise in the minds of some as to how satisfactory the separation of individual soil types may be. One investigator,[4] in

[4] Pendleton, "A Study of Soil Types," U. of Cal. Pub., vol. 3, No. 12, p. 369

an introductory statement to a study of soil types by one of his students, says that he doubts the validity of the U. S. Bureau of Soils method of soil classification and mapping and he cannot see how such methods can serve us in scientific work. Incidentally it may be remarked that the conclusion drawn from the experiments is that the Bureau of Soils types show up differences when studied from various angles.

It is hardly necessary here to enter upon a consideration of the system of classification of soils which is being followed by the Bureau of Soils except to say that there is no question in our minds but that the method of differentiating soil types which the Bureau is following is fundamentally sound. Of course, there are cases where it is difficult to draw sharp distinctions; there are variations in types which sometimes seem too great to us; there are some separations which seem too fine, which involve too much of the personal equation; but as a whole we believe the principles on which the Bureau separates soil types are sound. This conclusion has been arrived at from a very careful study of all methods of soil mapping and classification and has not been reached without considerable thought. Certain other systems of classification were seriously and critically considered but they could not compare with the Bureau method. Hence, even tho the mapping of soil types is not an exact science, as the Bureau itself would admit, and tho there is room for improvement in certain methods of procedure followed in making soil maps, the soil type as established by the U. S. Bureau of Soils, we believe should be the basis for all soil investigations.

In conclusion I would emphasize the statement that I am convinced that we cannot do scientific work on soils without knowledge of the soil type and that if the conclusions are not based on the specific soil conditions they are absolutely worthless. If we are to have a real soil science, a science which will rank with other sciences, pure or applied, we must get on a scientific and sound basis and we can do this only by basing our experiments, field, greenhouse, chemical, and bacteriological, on a *soil* foundation, or in other words, on soil type separations. As our knowledge of soils increases and our soil types become more definitely and accurately defined, our results will, of course, become more valuable. But at the present time, sufficient progress has been made, in our soil survey work, so that we can base all our experiments on typical soils, with the assurance that we will secure results applicable to that same soil under the same climatic conditions, and that the conclusions drawn will be of the utmost accuracy scientifically.

THE INFLUENCE OF IRRIGATION WATER ON THE COMPOSITION OF THE SOIL.[1]

J. E. GREAVES.[2]

Water is applied to a soil primarily to meet the needs of the growing plant. Incidentally, it materially modifies the chemical, physical, and biological properties of the soil. (1) Water may increase or decrease the available plant-food of the soil without changing the total quantity; (2) water may carry from a soil plant-food, thus leaving it intrinsically less productive; (3) water may carry to a soil phosphorus, potassium, and nitrogen, therefore increasing its total plant-food; and (4) water may carry to and deposit in a soil "alkali" salts which in time will render it barren. The magnitude of these changes will be governed by the nature of the soil, the composition of the irrigation water, and the intelligence with which each is handled. It is, therefore, the purpose of this paper to summarize briefly some results which have been obtained at the Utah Experiment Station during the past ten years.

It is generally accepted today that many of the reactions which occur in the soil and tend to render soluble the various mineral constituents thereof are due to bacterial metabolism. It is also agreed that bacterial activity is a function of the water content of the soil. Our work has shown that the correlation between the water-holding capacity of the soil, as determined by the Briggs' (6)[3] modification of the Hilgard Method, and the ammonia produced in a soil is very pronounced. Twenty-two soils varying widely in physical composition all gave a maximum production of ammonia when the soil contained 60 percent of its water-holding capacity. Either above or below this concentration there was a decrease in the ammonia found, as may be seen from the following summarized results (1). The soil which received 60 percent of its water-holding capacity is taken as 100.

Water in soil, percent of water-holding capacity	Ammonia produced	Water in soil, percent of water-holding capacity	Ammonia produced
10	2	60	100
20	8	70	78
30	32	80	57
40	68	90	49
50	85	100	45

[1] Contribution from the Department of Chemistry and Bacteriology, Utah Agricultural Experiment Station, Logan, Utah. Received for publication November 28, 1921.

[2] Chemist and Bacteriologist.

[3] Reference by number is to "Literature Cited," p. 212.

An excessive quantity of water is more injurious than is an insufficient quantity. The results as obtained for this same soil for nitrification are given below:

Water in soil, percent of water-holding capacity	Nitrates found	Water in soil, percent of water-holding capacity	Nitrates found
10	11	60	100
20	17	70	40
30	31	80	9
40	62	90	0
50	85		

Small quantities of nitrates were being produced when the soil contained only 10 percent of its water-holding capacity of water; but when this is increased to 90 percent nitrification ceases. Therefore, an excessive quantity of water is more detrimental than is insufficient water. It is interesting to note that the optimum moisture content for soil for the production of many of our staple crops is nearly 60 percent of the water-holding capacity of the soil. (1, page 380.)

Under optimum conditions there may be produced from 50 to 100 pounds of nitric acid in an acre of soil during a season (5). This, when converted into a nitrate, becomes a valuable supply of food to the growing plant. This quantity of acid must of necessity liberate appreciable quantities of phosphorus and potassium in the soil which therefore becomes available to the growing plant. Therefore, keeping the soil supplied with 60 percent of its water-holding capacity of water is supplying the plant with both water and plant-food.

Moreover, the production of other acids by bacteria is dependent upon optimum moisture content. They obey the same laws. We find the quantity of carbonic acid produced in twenty-four hours in a good arable soil supplied with the optimum amount of moisture to be enormous. Some results indicate that this at times may be as much as 67 pounds per acre (7). The resulting carbonated waters would react on tricalcium phosphate of soil, forming more readily soluble acid phosphates, for tricalcium phosphate is four times as soluble in water charged with carbonic acid as it is in pure water:

$$Ca_3 (PO_4)_2 + 2\ CO_2 + H_2O = Ca_2H_2 (PO_4)_2 + Ca(HCO_3)_2$$

This would mean that sixty-seven pounds of carbon dioxid is capable of transforming 236 pounds of tricalcium phosphate into 280 pounds of the soluble diacid phosphate, provided all of the carbon dioxid is utilized for this purpose. This shows the tremendous potential solvent powers of bacteria.

Potassium occurs in soil mainly as silicates and is rendered soluble by the nitrous, nitric, sulfuric, acetic, lactic, butyric, and carbonic

acids generated by the bacteria. The last-named may react with inert potassium, producing available potassium according to the equation: $Al_2O_3K_2O.6SiO_2 + CO_2 + 2H_2O = Al_2O_3.2SiO_2 + 2H_2O + K_2CO_3$.

Where only sufficient water is added to a soil to moisten or even saturate it and none drains from the soil, plant-food remains in the soil to be utilized by the growing plant. But when more water is added than the soil can hold, it passes through the soil and carries with it the soluble minerals. The magnitude of this factor is exemplified by the enormous quantities of the various salts found in the waters of some lakes and oceans.

It is estimated that the rivers of North America carry to the ocean each year 474,000,000 tons of soluble constituents, a quantity sufficient to cover one hundred acres to a depth of nearly three thousand feet. Although the greater part of this is common salt and other non-valuable compounds, yet there are appreciable quantities of valuable salts, as is witnessed by the 33.4 pounds of potassium, the 22.8 pounds of nitrogen, and 3.5 pounds of phosphorus which we have found to be the average quantity contained in one acre-foot of the streams of the inter-mountain region. Even as much as 133.0 pounds of potassium have been found in some drain waters (4).

Carefully controlled experiments, extending over a period of nearly fifty years, have been conducted at the Rothamsted Experimental Station in England where the yearly rainfall is about 30 inches and the annual loss of nitrogen was found to be 35.5 pounds per acre. This is about the loss which experiments covering a period of ten years indicate occur at the Logan Greenville Experimental Farm where 25 inches and over of irrigation water is applied to a soil during a season.

The economic value of this is seen from the fact that this quantity of nitrogen in the form of a commercial fertilizer would cost \$10.55. Moreover, grain grown on soil from which the available nitrogen is being continually washed is low in protein. Undoubtedly, the great merits of our dry-farm wheats as bread-makers is due in a large measure to the fact that the scanty rainfall is not sufficient to remove the soluble nitrogen from the roots of the growing plants. Yet certain farmers in irrigated districts leach out the plant-food with irrigation waters and then wonder why their soils are not productive.

The Valley of the Nile has become famous in irrigation history not because it was among the first irrigated districts of the world, but due to its extremely fertile fields, the fertility of which has been maintained throughout the ages. Other soils just as fertile have become barren. The Valley of the Nile owes its lasting fertility to the flood

waters which carry to it rich deposits of silt each year. Hence, we find that a soil's fertility may increase and not decrease through correct irrigation practi[illegible]

Where water is applied [illegible] leaches from it, and as the water evaporates it deposits within the soil its soluble and insoluble plant-food.

The following results have been obtained during the last few years at the Utah Experiment Station (4) in a study of the irrigation waters of the Intermountain region.

Hundreds of samples of water representing fifty-eight streams the majority of which are extensively used for irrigation purposes, have been analyzed. These waters vary in potassium content from 59 parts per million to only .79 part per million. Slightly over one-half of the waters contained 5 parts per million. The importance of these results becomes more obvious when we examine the pounds of potassium carried to an acre of soil by two acre-feet of water. This varies from 266.6 pounds in the case of the highest to 4.4 pounds in the case of the lowest, with an average potassium content of 33.4 pounds per acre.

These results are not without economic significance, for the highest amount of potassium found would be sufficient to produce 370 bushels of corn, 230 bushels of wheat or 34 tons of sugar-beets. The average for the stream is sufficient to produce 47 bushels of corn, 29 bushels of wheat, or 4 tons of sugar-beets.

Many of the soils of the intermountain region are rich in potassium; hence, this element is not as important as is phosphorus, which, although used by the crop in smaller quantities, is nevertheless at times the limiting factor in crop production.

The total phosphorus of the irrigation waters analyzed varied from traces to 5.47 parts per million. The great majority of them, however, contained less than one part per million. The average in 2 acre-feet of the water from these streams was 3.46 pounds, for that from the wells, 3.36 pounds; and for that from the drains, 1.82 pounds.

The phosphorus in two acre-feet of the water from the richest stream is sufficient for the production of 175 bushels of corn, 120 bushels of wheat, or 33 tons of sugar-beets. In the case of all the other streams, while not as high, it undoubtedly plays a part in maintaining the phosphorus content of the soil.

Even more important than the phosphorus is the nitrogen of the waters, for nitrogen is the limiting factor of crop production in most of the soils of the Intermountain region. This varies from traces up to 24.3 parts per million. The average quantity of nitrogen in two

acre-feet of the irrigation water is 22.8 pounds, while that in the highest is 132.2 pounds per acre. This would be nitrogen enough to produce 186 bushels of corn, 114 bushels of wheat, or [illegible] tons of sugar beets.

Moreover, there are in most of the soils of Utah numerous aërobic and anaërobic nitrogen-fixing bacteria. Our work indicates that these may increase the soil nitrogen twenty to thirty pounds per acre yearly. The quantity fixed, however, depends, among other things, upon the water in the soil (1).

Water stated as percent of water-holding capacity	Nitrogen gain	Water stated as percent of water-holding capacity	Nitrogen gain
10	30	60	75
20	25	70	100
30	25	80	90
40	38	90	45
50	45	100	25

It is at its maximum when the water contained in the soil is between 60 and 70 percent of the soil's water-holding capacity, and when the soil becomes filled with water the actual gain is only one-fourth what it is when the optimum moisture content is maintained.

These results probably help to explain the remarkable productivity of many of the irrigated soils of the arid regions. Some of them have been producing crops undiminished in quantity for upward of fifty years, and there is no reason why a limited few soils on which the richer irrigation waters are being used cannot continue for another fifty or one hundred years to produce maximum crops.

In addition to potassium, nitrogen, and phosphorus irrigation water carries varying quantities of soluble salts which may at times be concentrated enough to become a menace when the water is used for irrigation purposes. For instance, of the fifty-eight (2, 3) streams examined, the majority of which were extensively used for irrigation purposes, we find that thirteen of these carried soluble salt in dangerous amounts, if interpreted in the light of Hilgard's criterion that irrigation water should not contain over forty grains per gallon (571.2 parts per million).

The total soluble salt content of these fifty-eight streams varied from 60 parts per million to 1,312 parts per million. Moreover, it was found that a stream may be comparatively free from "alkali" during part of the year, but at other times it may be heavily charged with it. The melting of snow in the mountainous region usually has the effect of freshening the water, but local rains often have the opposite effect. In addition, drainage water, especially from "alkali" soils, greatly increases the soluble salt content of the stream.

The magnitude of the problem which confronts the users of these waters and the speed with which the soils may deteriorate is made clear by two examples. In one instance, a stream carried sufficient salts in it that one acre-foot would deposit on the soil 3,581 pounds of soluble salts, or twenty such irrigations would reach the enormous sum of 71,600 pounds — sufficient, if allowed to accumulate, to render the soil barren. Another stream would carry to the soil in the same time and under the same conditions over 15 tons of salt.

It is therefore evident that the intelligent use of irrigation water is a complex problem which requires a knowledge of the chemical, physical, and biological properties of the soil, together with a knowledge of the composition of the water and its influence upon the chemical, physical, and biological changes going on in the soil. One user of irrigation water may make of it a tool for making the desert bloom like the rose, whereas another user may through its use transform the most productive fields into a barren waste.

LITERATURE CITED.

(1) Greaves, J. E., and Carter, E. G. Influence of moisture on the bacterial activities of the soil. *In* Soil Science, v. 10:361-387. 1920.

(2) Greaves, J. E., and Hirst, C. T. Composition of the irrigation waters of Utah. Utah Exp. Sta. Bul. 163. 1918.

(3) Greaves, J. E., and Hirst, C. T. Composition of the waters of the Intermountain region. *In* Jour. Ind. & Eng. Chem., v. 10:1001. 1918.

(4) Greaves, J. E., and Hirst, C. T. The phosphorus, potassium, and nitrogen content of the waters of the Intermountain region. *In* Jour. Ind. & Eng. Chem., v. 11:451. 1918.

(5) Greaves, J. E., Stewart, Robt., and Hirst, C. T. Influence of crop season and water on the bacterial activities of the soil. *In* Jour. Agr. Rsch. v. 9:293-341. 1917.

(6) Mosier, J. G., and Gustafson, A. F. Soil physics and management. J. B. Lippincott & Co., Philadelphia and London. 1918.

(7) Stocklassa, Julius. Biochemischer Krieslauf des Phosphat-Ions im Boden. *In* Centrbl. Bakt. (etc.), Abt. 2, Bd. 29:385-515. 1911.

A NEW MUCK SOIL PROBLEM AND ITS SOLUTION.[1]

M.E. Sherwin, R. B. Etheridge, and A. Dunham.[2]

The problem here set forth is presented because it is believed to be unique in the development of muck lands. A brief history of the land leading up to its present condition will, therefore, be given.

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1922.

[2] Professor of Soils, Instructor in Soils, and Fellow, respectively, North Carolina State College of Agriculture and Engineering, Raleigh, North Carolina.

LOCATION AND HISTORY

The area is situated in Beaufort and Washington Counties, North Carolina, and comprises a hundred square miles or less depending upon the particular character, or the intensity of that character, which might be considered as essential to the placing of the soil in the unique class herein noted. The several characteristics of the soil vary and do not appear in their greatest intensity coextensive with each other. Except when otherwise noted, the soil conditions mentioned in this paper are those of the muck soil on the Nissen Farms at Terra Ceia.

The agricultural development began with the dredging of canals, by private capital, prior to the first sale of these lands for agricultural purposes, about ten years ago. Considerable care was exercised by the development agent to sell the tracts only to buyers with sufficient capital to clear and complete the development.

To clear the land, the timber was cut and when dry, burned where it fell. "Stuck" corn was then grown and the land burned again the next spring. Two or three crops of corn were thus grown, after which the remaining stumps were pulled and together with remaining logs dragged into piles for a final burning.

At this time, the land was better drained by lateral ditches, usually ten to the mile, and cultivation with implements was begun. The yield of "stuck" corn probably averaged about fifty bushels per acre and this yield was maintained for a few years after cultivation began. The yields were then depressed and drainage became less effective. With the hope of remedying this condition, two lateral ditches were dug between each pair of original ditches making thirty ditches per mile. Notwithstanding these additional ditches, the land fails to drain properly.

FIELD OBSERVATIONS.

The muck layer originally averaged about four feet deep. Settling and decay have reduced this to about two and a half feet on the land which was first developed. The furrow slice drains well and is loose; but immediately below this, the soil remains extremely wet. Although no water will drain from it in a month's time, water can be squeezed out as from a sponge by pressing it in the hands, even after a long drought. It appears tight, close, and soggy. Corn roots will scarcely penetrate below the furrow slice, with the result that corn fires badly. Soybean roots penetrate the subsoil and withstand the unfavorable conditions somewhat better.

In September, 1921, the unfavorable soil conditions were found not to be uniformly bad in any single field. The worst fields were

found to be speckled wi[illegible] It was noted that the subsoil was wetter and more compact in the unproductive spots, tho a difference was not always evident in the surface soil.

Where much tramping by animals has been done the crops are uniformly poor. The running of a disc ten or twelve times across a field in the same track gives a strip of poor crop, due apparently to the increased packing of the subsoil. It seems that the less tillage the better, after a very moderate amount has been given. It seems also that tractors and heavy machinery which have given very favorable results on other muck lands will do this land considerable injury.

LABORATORY OBSERVATIONS.

In January, 1921, samples of soil were taken from one of these fields and sent to Washington, D. C. for a determination of its acidity. The lime requirement of these samples, as reported by the Bureau of Soils, is slightly in excess of one ton $CaCO_3$ per acre inch.

Another sample was sent to the Soils Laboratory of the North Caroline State College, where the following observation, were made: The colloidal matter of the soil was found to be negatively charged. It was also found to be precipitated by certain acids and acid salts. Thus, sulphuric acid, equivalent to 1 ton of sulphur per two million pounds of wet soil (the weight of about an acre 10 inches) causes perceptible clearing in twenty-four hours of a suspension which otherwise will not clear in several weeks. Larger applications of acid increase this rate of clearing. The breaking strength of puddled and dried briquettes made from this muck, to which sulphuric acid has been applied in puddling was diminished. Commercial acid phosphate used for fertilizer purposes when added at the rate of 50 tons per two million pounds of wet soil is about as effective as sulphuric acid equivalent to one ton of sulphur. Smaller applications than this did not show any effect on the rate of clearing. Lime and calcium carbonate caused the solutions in which these mucks were suspended to retain their full cloudy condition longer than the check solutions. These materials when used at the rate of one to five tons per acre increased the breaking strength of briquettes. Drying the soil at room temperature greatly reduces its power of absorption. The following tabulation shows the variation in the water-holding capacity of the soil before and after drying and when left in water at different temperatures:

Water-holding capacity as taken from the field........	264.93%
After being oven dried and then allowed to stand 4 days in water	18.30%

Same soil after standing 12 hours in water 80°C absorbed
additionally 41.22%
Total absorbed 59.52%

This effect of drying on the water-holding capacity is easily noticed in the field.

COMPARISON OF SOIL FROM PRODUCTIVE AND UNPRODUCTIVE SPOTS.

Samples of soil were taken from the productive and unproductive spots noted above for comparison in the laboratory. The following is a tabulated statement of results obtained in the preliminary tests:

	Productive	Unproductive
Colloidal matter *	51.26%	48.87%
Loss on ignition of soil	85.68%	89.09%
Loss on ignition of colloid portion	93.66%	94.29%
Loss on ignition of non-colloid portion	77.28%	84.11%
Capillary water capacity	438.93	646.73
pH (determined colorimetrically)	4.5	4.5 to 5

* Material which remained in suspension after standing 3 days was blown off. The residue was again agitated; left to settle another 3 days; and again blown off. Material thus blown off is termed "colloidal."

It will be noticed that the colloidal matter is slightly higher in the productive spots than in the unproductive spots. This is contrary to what was expected from the appearance of the soils. The loss on ignition of the colloid portion is nearly the same regardless of productivity and the loss on ignition of the total soil not strikingly different. The loss on ignition of the colloid portion is five to eight percent greater than that of the total soil and ten to sixteen percent greater than that of the non-colloid portion.

The percentage of capillary water absorbed is very high for both soils; but is decidedly higher in unproductive soil. A comparison of the amount of water absorbed by these soils with that absorbed by the soil previously examined indicates a very wide variation in the water holding capacity depending upon the location from which the sample is taken. Much more work must be done before we can state positively which is most characteristic of the entire area or what the extreme limits are within the area.

Pending further investigation, the recommendation of ridged cultivation has been made to aid field practice; the object being to dry a maximum amount of the soil, thus limiting its colloidal matter and reducing its water holding capacity. There is field evidence on somewhat similar soil at Wenona that this treatment will give good results.

AGRONOMIC AFFAIRS.

PROGRAM FOR THE ANNUAL MEETING.

President Call has announced that the program of the annual meeting of the Society, to be held in Washington, D. C., in November, will consist chiefly of the following symposia:

"Phosphorus as Related to Crop Production," in charge of Dr. Firman E. Bear, Ohio State University;

"The Improvement of Agronomy Teaching," in charge of Dr. W. C. Etheridge, University of Missouri;

"Experimental Methods as Applied to Field Tests," in charge of Dr. H. H. Love, Cornell University.

It is planned that the first of these symposia shall occupy the program for the first day, and the other two for a half-day session each on the second day.

An important item of business at the annual meeting will be the decision on the question of whether the American Society of Agronomy will accept the invitation which has been extended to it to become one of the charter members of the proposed "Federation of the Biological Societies of America." President Call and the Editor attended the conference which was held in Washington, D. C., on April 23rd, under the auspices of the Division of Biology and Agriculture of the National Research Council, at which the proposal to form the new Federation was adopted.

WINTER MEETING OF THE SOCIETY.

A joint meeting of the Society with Section O of the American Association for the Advancement of Science will be held in Boston, next December. There will also be a separate session of the Society, at which there will be a symposium discussion of the topic "Soil Toxicity in its Relation to Economic Crop Production." The symposium is being arranged by Dr. B. L. Hartwell, of the Rhode Island Experiment Station.

NOTES AND NEWS.

On April 1st, C. B. Hutchison, formerly Professor of Plant Breeding at Cornell University, removed to Davis, California where he will be Director of the Davis Branch of the University of California College of Agriculture, and Professor of Plant Breeding.

C. L. Finch, of the Bureau of Markets and Crop Estimates of the United States Department of Agriculture, will be in charge of the enforcement work under the Grain Standards Act, with headquarters at Chicago, as successor to A. W. Herger, who died recently.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 SEPTEMBER, 1922 No. 6

PROGRESS IN STANDARDIZING THE INTRODUCTORY COURSES IN SOILS.[1]

M. F. MILLER.[2]

The standardization of courses in agricultural subjects has been practically impossible, thus far, because of the rapidly developing body of subject matter and because, as applied sciences, these courses have been greatly affected by local conditions. It would seem, however, that a condition has been reached in which the introductory courses in certain of the more fundamental subjects, such as soils, field crops, and animal husbandry, have come to embrace practically standard bodies of subject matter and that the time is ripe for efforts toward standardization. If approximate standardization can be brought about, it will make possible more rapid progress in the improvement of the courses, both in the selection of subject matter and in methods of teaching, while at the same time the transfer of credits between institutions will be facilitated.

There is little doubt that the subject matter of the introductory course in soils is more nearly uniform than that of other introductory agricultural subjects. This is because it is an outgrowth of the basic sciences of physics, chemistry, biology, and geology. Probably the subject has depended too largely on these sciences and has not developed a sufficiently distinctive type of subject matter; but when allowance is made for variations in local conditions, the material included in standard soils texts is essentially the same. The effect of local and climatic conditions on the character of the subject matter must always be recognized, but in most cases these variations offer no great obstacle to standardization. When, however, climatic conditions differ as radically as those of the group of states lying west

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Professor of Soils, University of Missouri, Columbia, Mo.

of the hundredth meridian and those lying east of this line, a single course can scarcely be adapted to both sections. Doubtless the fundamental principles will be the same, but the problems of soil moisture storage, of irrigation, and of alkali control are of paramount importance in the West while the problems of fertilizer practice are of great significance in most of the eastern states. It seems probable, therefore, that the subject matter and practicums must be materially modified and rather distinct courses developed for the two regions.

The conference which was held at Lexington, Kentucky, in June 1920, was made up largely of representatives of the eastern group of states, and the course outlined there was intended primarily for use in that region. At about the same time a conference of men from the western states was held on the Pacific Coast, so that the prospects of developing distinct standardized courses for the two regions are very good. As three-fourths of the states are represented in the eastern group, I suppose the greatest interest centers upon the type of course best suited to this region.

The Lexington conference attempted to outline the essentials of a 5-semester-hour required sophomore course, or its equivalent, consisting of three class periods, one quiz or discussional period, and one laboratory or practicum period each week. Little attempt was made to outline the details of the subject matter of the course since it was taken for granted that this would embrace approximately what is included in standard texts written by men in the eastern region. The laboratory and practicum work was, however, rather definitely outlined. It included studies of minerals and rocks, some physical studies and some chemical studies, together with certain practical exercises and field trips. The fundamental idea in arranging the laboratory outline was to avoid lengthy laboratory exercises designed to teach laboratory technique and to substitute material which would give definite information about soils. The purpose of the entire course, as conceived by the conference, was to impart as much information to the student as possible and to avoid making it simply a preparatory course for further soils work. Since most of the students who take such a course will secure no further training in the subject, it is only fair to give a well-rounded course including a general survey of the field, one which is designed to meet the needs of the majority of the students.

It is, of course, too early to report any marked progress in the adoption of such a course in the various institutions, although a brief statement of the manner in which the soils instructors are

reacting to the plan, seems worth while. In answer to an inquiry, in the form of a brief questionnaire sent to the agricultural colleges throughout the country, 38 responded, 30 from the eastern states and 8 from the western states. The following is a brief summary of the most significant facts brought out by these replies.

Approval or disapproval of course plan.	Eastern group.	Western group.
Distinctly favorable	21	....
Favorable with modifications	6	7
Not distinctly favorable	3	1
Number using the course.		
Using course as outlined	5	....
Using course with slight modification	6	1
Giving a somewhat similar course but with material modifications	8	6
Giving a dissimilar course	11	1
Credit hours in course.		
Three credits or less	8	1
Three to five credits	18	5
Six credits or more	4	2
Year in which course is offered.		
Sophomore	19	6
Junior	8	2
Divided between two years	1	....
No information	2	....

It is surprising that so large a percent of the men reporting are in favor of the general plan. As only fifteen institutions were represented in the Lexington conference, all of the others were made familiar with the details of the plan through written and published statements. In spite of this fact, 70 percent of all the eastern institutions reporting, are favorable to the plan, while most of the remainder favor it with some modifications. Of the western institutions reporting, all except one are favorable to the plan, although as would be expected, most of them suggest that modifications are necessary in order to adjust it to western conditions. It is of interest to note that of the two men who dissented at the Lexington conference, one writes that he has practically concluded that the plan is a wise one, while the other offers no objections, except to insist that he still favors a larger amount of chemical and biological work than is provided in the laboratory outline. It may be of further interest to state that several of the institutions reporting were already giving practically the course as outlined or one very similar to it. Of eastern men who have been able to give the course a trial, either as outlined or with slight modifications, all favor it; although

most of them admit that the time has been too short to form a satisfactory opinion or to suggest definite changes. It should be said, too, that most of the men who are giving a course quite dissimilar to the one suggested are nevertheless in favor of the plan and express themselves as moving in that direction.

As might be expected, there is some difference of opinion with reference to the place which such a course should occupy in the curriculum. Slightly more than 60 per cent of the eastern men and 75 per cent of the western men favor the sophomore year, the remainder favoring either the junior year or a division of the course between the two years. Those who favor the junior year do so largely because of a desire to secure greater training in the basic sciences. It must be admitted that, so far as the efficiency of technical soils instruction is concerned, physics, geology and at least 10 hours of chemistry should be prerequisites; but for such a course as the one outlined, general inorganic chemistry and physics are the only courses absolutely essential. On the whole, the advantages of offering the course in the sophomore year seem to outweigh the advantages of more thorough training in the basic sciences. When thus offered, a better foundation is laid for advanced courses in field crops, and horticulture. It is also possible to reach a large number of students who return to the farm at the end of the sophomore year, and, a matter which is of special interest to soils instructors, it offers greater opportunity for students to take advanced soils courses.

The plan to make this introductory soils course one which meets the needs of the student who will take no further work in soils seems to have been well received. Several men comment on the wisdom of this plan and no objections are offered. There is little doubt that this matter is of fundamental importance and that it will utimately be favored in the majority of the institutions.

The greatest difference of opinion centers on the character of the laboratory work and practicums. Several men still contend for a considerable amount of detailed laboratory work, including much of a chemical nature. It must be admitted that such laboratory exercises have much to commend them, but it is practically impossible to arrange such a laboratory course which does not waste the average student's time in physical exercises of doubtful value, or consume much of his effort in learning the technique of chemical determinations.

Several men comment on the value of having the laboratory

work parallel that of the class room, which is made possible by this plan. Certainly this is good pedagogy. It is doubtless one of the strong features of the course. Others mention the importance and popularity of field trips and practical exercises which make it possible for the student to learn something of soils in the field. Such a form of instruction, properly organized, cannot but interest the student, and give him more valuable information than much of that which has heretofore been offered in the laboratory. It is a part of the attempt to give a well rounded course of particular value to the majority of the students.

The allotment of time between class, quiz and laboratory periods has not met with universal approval. This is because under some curricula it is impossible to arrange the suggested time allotment, because some men still insist on more laboratory work than the plan provides and because some object to devoting one whole period each week to a quiz. It is of course impossible to meet all of these objections and doubtless it is unnecessary. The utilization of the quiz period may well be left to the discretion of the individual instructor. The whole matter is one of pedagogy. If men prefer to use a part of each day as a discussional or quiz period there should be no objection. It is probably sufficient that the matter has been brought to the instructor's attention. It will serve to bring about better teaching and more attention to the pedagogy of the subject, which after all are among the greatest benefits to be derived from a standardized course. One instructor suggests that the success of the course as outlined depends largely upon the ability of the teacher to hold the interest of the students. There is little doubt that with only one laboratory period in a five hour course, much more depends upon the instructor than where more laboratory work is given. He must be alert. He must study methods of presenting subject matter. He can no longer depend upon a routine of laboratory work to consume the student's time.

The replies received from the various institutions, regarding the desirability of adopting such a course, show a remarkable unanimity of opinion. Of those who have given the plan a trial, all are in favor of its continuance. Just how generally such a course will be adopted in detail, only time will tell. Doubtless, many institutions will find it impossible to accept it exactly as outlined because of curriculum difficulties, since every curriculum is a compromise. Sometimes too there may be local difficulties which may prevent its adoption. On the whole, however, the indications are that con-

siderable progress is being made and the course as outlined seems to offer a good basis upon which to work toward ultimate standardization.

CONTROL OF COTTON WILT BY THE USE OF POTASH FERTILIZERS.[1]

LOY E. RAST.[2]

During the spring of 1920, nine five-acre fertilizer experiments with cotton were located on different plantations near Scott, Arkansas. The soil is alluvial river land known as "Lonoke very fine sandy loam." On each of these areas different fertilizers were used at each place; but all were applied at the rate of 500 pounds per acre.

FIG. 1. Healthy, vigorous plants on left were fertilized; on right, no fertilizer was used and all plants died.

One grower used 500 pounds per acre of a mixture containing 10 percent phosphoric acid, 3 percent nitrogen and no potash. The cotton plants in this field on both the fertilized and unfertilized areas in 1920 died so badly that no record was kept of the yield of cotton produced. The experiment was to continue on the same area for

[1] Paper read at the meeting of the Society held at New Orleans, La., November 8, 1921.

[2] Agronomist, Little Rock (Arkansas), office, Farm Service Bureau, Southern Fertilizer Association.

five years and something had to be done in order to get any results that would justify the expense for fertilizers. The writer suggested that 500 pounds of the same fertilizer as was used in 1920 (containing 10 percent available phosphoric acid, 3 percent nitrogen and no potash) be mixed with 500 pounds of kainit containing 12.5 percent potash. This mixture contained, as shown by analysis, 5 percent available phosphoric acid, 1.5 percent nitrogen and 6.25 percent potash, it was applied in the spring of 1921, at the rate of 1000 pounds per acre, before planting. The plants on the unfertilized area began to die long before they were mature and were evidently infected with the disease "cotton wilt." By harvest time, no less

FIG. 2. Part of the field to which potash fertilizer was applied, no wilted plants.

than 95 percent of the plants on the unfertilized area were dead and not a dead plant could be found in any part of the field where the fertilizer was used.

The fertilized area produced 1127 pounds of seed cotton per acre; whereas, the disease-infected part of the field to which no fertilizer was applied produced only 225 pounds of seed cotton per acre. Plants on an adjoining area to which 500 pounds per acre of fertilizer containing 10 percent available phosphoric acid, 3 percent nitrogen and no potash was applied before planting and to which 500 pounds per acre of kainit was used as an additional application after the plants

were up and growing, were equally resistant to the disease and just as prolific.

Certainly, the control of cotton wilt by the use of commercial fertilizer was something new. It was evidently due to the potash in the fertilizer, but even the manufacturers and dealers of this material had never made such a claim for it. To preclude any chance of mistaken identity of the disease, Dr. John A. Elliott, Plant Pathologist

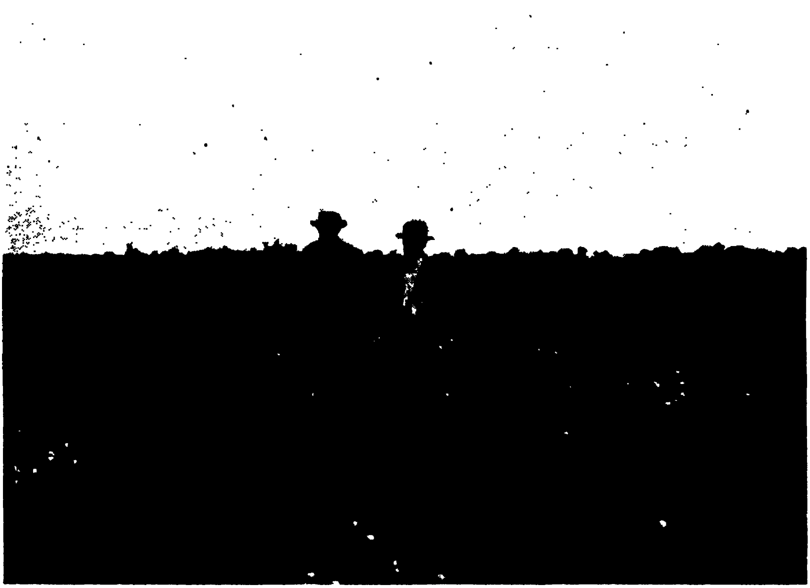


FIG. 3. Part of the field to which no fertilizer was applied. All of the plants died of wilt.

for the Arkansas State Experiment Station, was summoned and after a thorough inspection of the field, he wrote:

"Your experiment on Mr. ———————'s place was indeed striking. There is no doubt that the field is heavily infected with wilt, as practically every cotton plant on the check plot was dead or dying of the disease when I saw it. The plants on the adjacent kainit plot were remarkably free from wilt infection and I doubt if there was any material reduction in yield on this plot due to wilt. I do not attempt to make an explanation of the facts but to all appearances the treatment the kainit plot received enabled the plants this year to very largely escape wilt infection."

These experiments will be continued and various kinds and quantities of potash, both alone and in combination with other plant foods, will be used to determine their effectiveness in controlling this disease.

GRAINS GROWN IN COMBINATION FOR GRAIN PRODUCTION.[1]

C. A. Zavitz.[2]

For over a quarter of a century, various experiments in growing grains in mixtures for grain production have been conducted at the Ontario Agricultural College. It is interesting to observe in connection with the crop production of Ontario that the greatest areas in 1921 were used for the growing of oats, fall wheat, mixed grains, barley, husking corn, spring wheat, buckwheat, rye, peas, and beans, in the order here given. 618,289 acres were used for mixed grains in the past season, this acreage being almost equal to that used for the growing of winter wheat. It will be seen, therefore, that the growing of grains in definite combinations is occupying an important place in crop production in the Province of Ontario.

For six years in succession an experiment was conducted at the Ontario Agricultural College by growing oats, barley, spring wheat, and peas separately and in various combinations for the production of grain. Six mixtures having two classes of grain in each mixture, four having three classes of grain in each mixture, and one having all four classes of grain in combination were used each year. This made in all eleven mixtures, besides the four grains grown separately, requiring in all, fifteen plots. The experiment was conducted in duplicate, thus making thirty plots each year or one hundred and eighty plots in the six-year period. Varieties were selected which matured uniformly. The varieties were cut when they reached the proper stage of maturity and when dry were taken to the experimental barn and threshed. The grain was then cleaned and carefully tested, and the results recorded. The following table gives the average results in yield of straw and in yield of grain per acre of each of the eleven different mixtures as determined by twelve separate tests conducted in the six-year period. It also gives the comparative average results for the same grains when grown separately:

[1] Paper read at the meeting of the Society held at Toronto, Canada, December 28, 1921.

[2] Professor of Agronomy, Ontario Agricultural College, Guelph, Ontario, Canada.

TABLE 1.— *Yields of grains grown separately and in mixtures.*

Varieties of grain grown in mixtures.	Yield per acre. Straw. Grown separately in (tons).	Straw. Grown in mixtures (tons).	Grain. Grown separately in (lbs.).	Grain. Grown in mixtures (lbs.).
1. Barley and oats	1.56	1.74	1,935	2,261
2. Barley, peas and oats	1.47	1.67	1,489	2,101
3. Barley, wheat and oats	1.47	1.72	1,683	2,067
4. Peas and oats	1.52	1.77	1,873	1,988
5. Barley, peas, wheat and oats	1.43	1.71	1,682	1,955
6. Wheat and oats	1.52	1.68	1,624	1,921
7. Peas, wheat and oats	1.44	1.73	1,642	1,860
8. Barley and peas	1.33	1.56	1,740	1,760
9. Barley, peas and wheat	1.32	1.57	1,553	1,665
10. Wheat and barley	1.33	1.41	1,491	1,558
11. Peas and wheat	1.29	1.37	1,429	1,322

The foregoing results show that a mixture of barley and oats gave the highest production of grain, the average yield per acre being 2,261 pounds as compared with 1,322 pounds produced from a combination of peas and wheat under similar conditions. This makes a difference in yield per acre of 939 pounds of grain produced by the barley and oats in comparison with that obtained from the peas and wheat. It is interesting to note that, with only one exception, the grains grown in combination gave a greater yield per acre than the average production of the same grains when grown separately. As for instance, barley and oats when grown together gave 326 pounds of grain per acre more than the average of the two grains when grown separately. The only exception to the rule of the comparatively higher returns from the mixed grain is in the case of peas and wheat when the mixture gave an average of 107 pounds per acre less than the average of the two grains when grown by themselves. In the yield of straw, the mixed grains came the highest in every instance. The greatest yield per acre of straw was produced from the peas and oats grown in combination.

From the general results, it appears that the different classes of grains exerted an influence on the productiveness of the mixtures in the following order, namely:— oats, barley, peas and wheat, the oats having the greatest influence and the wheat the least. From a study of the detailed results of the experiment in growing the grains separately and in different combinations, it was found that in about 90 percent of the experiments the mixtures produced a greater yield per acre in comparison with the same grains when grown separately. Barley and oats, when grown in combination in the six-year experi-

ment, gave 193 pounds of threshed grain per acre more than the highest yielding grain when grown alone.

Having learned as the result of experimental work that a mixture of barley and oats was well adapted to a large production of grain, it became of importance to know the best proportions of these grains to use in combination to give the most satisfactory results. In the solution of this question alone, experiments have been conducted annually for fifteen years, there being three sets of experiments each running for five years. In all twenty-five different proportions of barley and oats have been carefully tested in each of five years. As the result of three separate tests, it was found that the greatest yield of grain per acre was produced by using a mixture of one bushel of barley (48 pounds) and of one bushel of oats (34 pounds) per acre, making a total of 82 pounds of seed per acre.

While there has been quite a decided advantage in growing different classes of grain in combination, there has been practically no advantage observed in numerous other experiments in growing in combination different varieties of the same class of grain. For instance, the results of experiments in growing different varieties of winter wheat in combination for five years in succession showed no advantage over growing the same varieties separately. This held true also in regard to the growing in combination different varieties of oats and again in growing together different varieties of barley, although in the case of barley, there was a very slight advantage from growing the varieties in combination.

Extensive experiments in the testing of different varieties of barley and of different varieties of oats were conducted over a series of years in order to ascertain the most suitable varieties for using in combination. In one test alone there were nineteen different combinations of varieties grown in duplicate tests in each of five years. An ordinary-ripening variety of barley and an ordinary-ripening variety of oats will not ripen at the same time. It is necessary to either use a six-rowed barley and an early variety of oats or a two-rowed barley with a late maturing oat according to the varieties which have been tested at the Ontario Agricultural College. The results of the experiments have shown that the highest yield and the best satisfaction throughout has been obtained from a high yielding six-rowed barley and a high yielding early oat. The O. A. C. No. 21 barley when grown in combination with the O. A. C. No. 3, the Alaska, or the Daubeney oats has given excellent returns.

Some farmers have been under the impression that, if a com-

paratively small quantity of rye, or wild goose spring wheat, or flax, was added to a mixture of oats and barley, they would receive in the resultant crop, not only as large a yield of oats and barley *as if these two grains had been grown without any additional seed, but that they would obtain a fair yield of rye, or goose wheat, or flax, in addition.* Results of numerous experiments have shown that this has not been the case and that so far no additional grain of any kind has been used with a standard mixture of barley and oats which has not caused an actual reduction in the total yield of grain per acre.

In experiments in which from eight to twelve different classes and varieties of grain have been grown in combination and in which the resultant crop has been separated into its different factors, it has been found that the greatest influence in high production has been exerted by barley and the second highest by oats.

From the various lines of experimental work which have been carried on, it will be seen that, if the right varieties and the right proportions of barley and oats are grown together under favourable circumstances, a comparatively high yield of the mixed grain may be expected.

EFFECT OF FERTILIZATION ON THE GROWTH OF SUGAR BEETS ON SOME MICHIGAN MUCK SOILS.[1]

M. M. McCool and Paul M. Harmer.[2]

There are several million acres of organic soils in Michigan. Usually these are spoken of as mucks; whereas in certain other states similar formations are termed peats. Only a relatively small percent of these lands is developed and inasmuch as many deposits are of high grade their development is only a question of time. Inadequate drainage, occurrence of frost, and lack of knowledge concerning their fertilization and crop adaptations, account for their undevelopment. Thus, it is desirable to know whether or not it is feasible to grow a relatively frost resistant and heavy cash crop such as the sugar beet on these lands.

The production of sugar beets in Michigan has been extensive for many years. In fact Michigan is one of three leading beet-sugar producing states, the average acreage of land devoted to this

[1] Paper read at the meeting of the Society held at Toronto, Canada, December 28, 1921.

[2] Professor of Soils and Assistant Professor of Soils, respectively, Michigan Agricultural College, East Lansing, Mich.

crop amounting to about 113,000. Sixteen factories, whose daily slicing capacity ranges from 500 to 1,500 tons each, refine the sugar from these beets.

The sugar beet producing areas are confined mainly to the Saginaw Bay and central Michigan sections of the State; although appreciable acreages are grown in eastern, southeastern and western Michigan. The acreage of land devoted to this crop and the tonnage obtained are given in Table 1, after V. M. Church.

TABLE 1.—*Sugar beets in Michigan — Total acreage, total yield, and average yield per acre — 1909 to 1920.*

Year.	Area harvested (acres).	Average yield per acre (tons).	Total production (tons).
1909	78,779	9.0	708,000
1910	117,500	10.3	1,208,000
1911	145,837	9.9	1,444,000
1912	124,241	6.8	839,000
1913	107,965	9.0	955,000
1914	101,263	8.5	857,000
1915	122,000	8.2	998,000
1916	99,619	5.5	544,000
1917	82,151	6.4	462,000
1918	114,975	7.9	890,000
1919	123,375	9.82	1,211,000
1920	129,400	8.6	1,106,000
Average	112,258	8.3	920,000

The majority of the beets are grown on the fine textured soils that have been weathered under rather poor drainage conditions, the topography being flat to gently undulating, this being especially true of the Saginaw Bay and eastern and southeastern Michigan areas. For several years this crop has been grown successfully on a small acreage of shallow muck or peat soils. It is generally considered that this can not be accomplished on the deeper mucks inasmuch as beets of inferior quality and low sugar content are produced.

Fertilizers have been used very sparingly for the production of sugar beets. The average rate of application is about 125 pounds per acre of low grade complete fertilizer. This is too parsimonious in case of many soils and it is probable that the rather low average yield obtained, as well as the increasing difficulty encountered in connection with diseases, can be ascribed to it.

OUTLINE OF PROJECT

In view of the general situation with respect to muck lands it was deemed advisable to inaugurate field experiments on the effect

of fertilizers on the tonnage, sugar content and percent of purity of beets grown on them. The fields upon which these investigations are being conducted are widely scattered and represent formations of different nature. All are located on extensive areas of muck and all are on deposits four or more feet in depth in the locality of the fertilizer plots.

The field at Buchanan is located on a well decomposed muck in the southwestern part of the State. It has an organic matter content of 74.85 percent and as ash content of 25.15 percent. The finely divided material is quite black in color, yet the soil is strongly acid. This muck is very impervious to water, crops grown on it in 1921 suffering for lack of drainage even to the edge of the drainage ditch, where the water level in the ditch was three or more feet below the surface. This lack of drainage is evident in the low crop yield reported below. The field had been cropped for several years and was in marked need of fertilization.

The Homer muck field is part of an extensive area in south central Michigan. This muck contains 83.24 percent of organic matter and 16.76 percent total ash. The material is quite woody and porous and is very slightly acid. This field is part of a tamarack swamp which burned over about 20 years ago and has been used to some extent for pasture since that time. It was broken for the first time in 1920, the sugar beets reported below being the first crop grown.

The field at Imlay City is on a rather woody, porous muck in the eastern part of the state. It has an organic matter content of 82.27 percent and a total ash content of 17.73 percent. The soil is not acid. It has been cropped for several years and shows considerable response to fertilization.

The field at Lum is only eight miles distant from that at Imlay City, yet the character of the deposit is markedly different. The muck is very well decomposed and quite firm under foot. It has an organic matter content of 68.13 percent and an ash content of 31.87 percent. The soil is not acid. The field has been cropped for a long period of years and is in marked need of fertilization.

Standard fertilizer treatments were given to the different portions of the fields. Nitrogen was added as nitrate of soda at the rate of 100 pounds per acre, phosphoric acid as 250 pounds of 16 percent acid phosphate and potash as 200 pounds of potassium chloride per acre respectively. Twelve tons of manure usually were applied per acre. The materials were distributed by means of fertilizer drills.

EXPERIMENTAL RESULTS

Tonnage. The yields of roots in tons per acre from the variously treated plots of four deposits are given in Table 2. The Buchanan muck is markedly deficient in potash as shown by the remarkable response of several other crops, notably sunflowers, corn, mangels and stock carrots, to its application. The sugar beet yield was increased by the potash, yet the crop was practically a failure. Thus, fertilization may not overcome other deficiencies, such as drainage.

TABLE 2.—*Effect of different fertilizers on the yield of sugar beet roots.*
(Expressed in tons per acre.)

Treatment.	Buchanan.	Lum.	Imlay City.	Homer.
None	0.7	3.5	5.9	11.7
Nitrogen	1.1	3.7	7.0	13.3
Phosphorus	0.4	3.2	7.7	13.4
Potassium	4.5	12.3	8.3	15.9
Nitrogen and phosphorus	0.9	4.5	7.3	11.0
Nitrogen and potassium	3.5	16.6	5.6	16.3
Potassium and phosphorus	2.8	14.1	7.5	17.4
Nitrogen, potassium and phosphorus	3.8	16.2	8.7	15.4
Manure	3.1	15.5	10.4	17.5

The Lum field responds amazingly well to applications of potash alone; but while applications of either nitrate of soda or acid phosphate alone do not result in increased yields, when either of these or both are applied along with potash they are quite effective.

The Imlay City muck was quite porous and too loose to yield best results with sugar beets; yet the mineral fertilizers increased the yields somewhat and the manure almost doubled the yield obtained from the check plots.

Lastly, the Homer muck appears to be an ideal one for the production of this crop. The unfertilized plots averaged eleven and nine-tenths tons per acre of roots. The fertilizer treatments, except where a mixture of nitrate of soda and acid phosphate was applied, increased the yields appreciably, as did stable manure. Potash was more effective than either nitrogen or phosphoric acid.

The yield of the tops was determined in the first three fields (Table 3).

TABLE 3.—*Effect of different fertilizers on yield of sugar beet tops.*
(Expressed in tons per acre.)

Treatment.	Buchanan.	Lum.	Imlay City.
None	1.1	5.2	6.4
Nitrogen	1.9	4.1	6.5
Phosphorus	0.7	3.6	11.1
Potassium	3.5	6.1	7.4
Nitrogen and phosphorus	1.6	5.6	11.3
Nitrogen and potassium	4.7	5.5	6.5
Potassium and phosphorus	3.2	5.2	9.6
Nitrogen, potassium and phosphorus	2.9	5.1	10.7
Manure	2.1	4.7	8.6

Acid phosphate decreased the yield of tops produced on the Buchanan and Lum muck, whereas it increased it strikingly in case of the Imlay City deposit. When applied to the Buchanan soil, nitrate of soda stimulated leaf development somewhat in all cases except where acid phosphate was also used, whereas its effect was less consistent when applied to the Lum and Imlay City muck areas.

Sugar content. The above results show that satisfactory yields of sugar beets may be obtained on some muck soils especially when properly fertilized. It is equally important to know the sugar content of the beets grown under different conditions of soil and fertilization.

It has long been recognized that the element potassium is important in connection with the elaboration and transportation of carbohydrates in plants or that the presence of proper amounts of this element results in a more efficient leaf surface. A large leaf development of plants, such as the sugar beet and peppermint, for example, does not necessarily mean a high sugar or oil content. If the potassium is somewhat deficient the converse may result.

TABLE 4.— *Effect of different fertilizers on the sugar content.*
(Expressed in percent sugar in the beet.)

Treatment.	Buchanan.	Lum.	Imlay City.	Homer.
None	13.8	10.8	14.4	13.8
Nitrogen	14.2	12.3	15.1	12.2
Phosphorus	10.0	12.9	14.2	12.4
Potassium	16.7	14.1	15.5	13.4
Nitrogen and phosphorus	11.8	11.2	14.4	12.8
Nitrogen and otassium	16.4	15.8	14.9	12.9
Potassium and phosphorus	14.2	15.9	14.2	14.4
Nitrogen, potassium and phosphorus	15.5	16.2	13.3	14.0
Manure	13.0	14.8	15.3	14.3

In the case of the Buchanan muck (Table 4) the addition of acid phosphate in a lowering of the sugar content of the beets, whereas nitrate of soda alone and also with acid phosphate increased it somewhat and when added along with the potash its effect was slightly depressing. The application of potash to this land proved to be the most effective in increasing the sugar content of the beets.

At Lum, the highest sugar content was attained in the beets grown on the land fertilized with a mixture of nitrate of soda, acid phosphate and potassium chloride. A mixture of nitrate of soda and acid phosphate did not appear to be as effective as did these fertilizers when used singly. The addition of the muriate of potash resulted favorably in all cases.

The differences in the sugar content of the beets grown on the various plots of muck near Imlay City were not great nor were the effects of the fertilizers consistent. At Homer, the nitrate of soda and acid phosphate when used singly or together without the potash appeared to have a depressing effect. The sugar content of the beets grown on the control plots and those produced on the plots receiving potash or manure varied but slightly.

Acre production of sugar. The amount of sugar produced per acre under the different conditions is interesting in that it shows the combined effect of fertilization on two variables, yield and sugar content. We have made such calculations and summarized them in Table 5.

TABLE 5.—*Effect of different fertilizers on the yield of sugar.* (Expressed in pounds per acre.)

Treatment.	Buchanan.	Lum.	Imlay City.	Homer
None	129	504	1,133	2,153
Nitrogen	208	607	1,409	2,163
Phosphorus	53	550	1,458	2,215
Potassium	1,002	2,312	1,715	2,841
Nitrogen and phosphorus	142	672	1,402	1,877
Nitrogen and potassium	765	3,497	1,113	2,804
Potassium and phosphorus	530	2,989	1,420	3,341
Nitrogen, potassium and phosphorus	785	3,499	1,543	2,875
Manure	537	3,059	2,122	3,336

The most impressive points brought out with respect to the Buchanan muck are the effects of potash and the failure of this soil to produce satisfactory yields of sugar beets. At Lum, the action of potash is almost amazing, its presence changing this soil from a worthless condition to a satisfactory one so far as this crop is concerned. In case of the Imlay City muck, manure resulted in the largest sugar production on an acre, followed by potash alone and a mixture of the mineral substances carrying the three elements of plant food, nitrogen, phosphorus and potassium. The lowest amount of sugar produced was obtained from the plot that received nitrate of soda and muriate of potash. The salient features of the Homer project are the efficiency of stable manure, the favorable action of potash both alone and in conjunction with acid phosphate and the depressing effect of nitrate of soda when added together with either acid phosphate or the muriate of potash.

Purity. From the standpoint of the beet sugar manufacturer the sugar content and coefficient of purity are the factors which determine the value of beets for sugar-making purposes. A considerable per-

centage of the total weight of the beet consists of soluble solids, of which sugar forms the largest portion. Beets testing 12 percent sugar and 80 percent coefficient of purity, mean that 12 percent of the total weight of the beets is sugar and that 80 percent of the total soluble solids is sugar. The percentage of purity of the beets grown under various conditions is given Table 6.

TABLE 6.— *Effect of different fertilizers on the purity.*
(Expressed in percent.)

Treatment.	Buchanan.	Lum.	Imlay City.	Homer.
None	90.6	79.2	83.1	86.8
Nitrogen	89.1	80.6	83.9	84.0
Phosphorus	82.4	85.2	82.9	82.6
Potassium	94.6	83.8	88.1	85.2
Nitrogen and phosphorus	86.1	71.8	83.5	83.5
Nitrogen and potassium	91.5	87.8	81.0	82.9
Potassium and phosphorus	95.2	88.8	83.4	85.0
Nitrogen, potassium and phosphorus	93.5	85.8	79.6	86.2
Manure	87.3	87.9	85.8	86.0

The beets produced on the Buchanan muck were abnormal with respect to purity except in two instances. Both nitrate of soda and acid phosphate caused a depression in purity except where combined with potash. At Lum the lowest purity was recorded in the beets from the land treated with a mixture of nitrate of soda and acid phosphate, followed in turn by those from the unfertilized nitrate of soda and muriate of potash plots respectively, the differences in the purity of the others being small. The results are not consistent in case of the beets grown on the Imlay City muck. The highest purity was attained in the beets from the potash treated plot and those containing the most impurities were grown on the complete fertilizer land. The application of stable manure resulted favorably.

In all cases the beets from the unfertilized Homer muck contained less impurities than those grown on the treated land, although the differences were slight with the exceptions of those produced on the plots treated with acid phosphate alone, a mixture of nitrate of soda and acid phosphate and nitrate of soda and muriate of potash respectively.

THE EFFECT OF SUDAN GRASS ON THE BIOLOGICAL PROCESSES IN THE SOIL.[1]

Paul Emerson and Roland D. Fletcher.[2]

It is a well known fact that plant foods are constantly disappearing from soils regardless of the cropping methods which are followed. The greatest loss in a well regulated system of soil management is by assimilation by the plants and consequent removal from the soil. Some crops may remove more plant food than others and are spoken of as normal or heavy soil feeders according to the amount of soil-derived elements required for their growth. Sudan grass may be classed as a heavy soil feeder. It has an ash content of over 6 percent,[3] is very rank in growth and therefore may remove large amounts of soluble plant food from the soil.

Many workers have established the principle that there is a more or less direct relationship between the available plant food in the soil and its biological activities. It is usually assumed that in the competition for food between the soil organisms and the growing plant, the former may be limited in their activities by the needs of the latter. It becomes of interest therefore to determine what effect a heavy soil feeder like Sudan grass has upon the biological processes in the soil and, further, should the effect be detrimental, what methods of procedure will be necessary to correct the trouble.

The Department of Farm Crops of the Iowa Agricultural Experiment Station for a number of years has been studying methods and rates of seeding Sudan grass for hay and for seed, using a four year rotation of Sudan grass, soy beans, small grains and legumes. As these plots were of the same general soil type, and have each completed the rotation, they furnished an excellent basis for bacteriological determinations. Accordingly, a study was made of the biological activities of three plots, first a clover plot on which Sudan grass had been grown three years previously, second a Sudan grass plot and third, a virgin prairie soil. The study was extended to include the effect of additions of some common fertilizing materials both on the biological processes and on plant growth.

[1] Paper read at the meeting of the Society held at Toronto, Canada, December 28, 1921.

[2] Assistant Professor of Soils and Assistant in Soils, respectively, Iowa State College, Ames, Iowa.

[3] Farmers Bulletin 1126 of the U. S. Department of Agriculture shows an ash content of 7.94 percent and a yield of two to nine tons per acre.

Representative samples were secured in the fall from the Sudan grass plot, the clover plot and also from an area adjacent to these plots, which according to all available records was virgin prairie soil. These samples were taken shortly after the Sudan grass crop had been removed. This plot therefore was bare while the other two were supporting growing grasses. The samples were taken according to approved methods and thoroughly mixed before use for the bacteriological, chemical and greenhouse determinations.

LABORATORY STUDIES

The total nitrogen, phosphorus and carbon content of these soils together with the nitrate-nitrogen and lime requirement, determined by the usual methods, are shown in Table 1.

TABLE 1. — *Analyses of field soils.*

(Expressed in pounds per acre, based on 2,000,000 pounds per acre of soil.)

	Total nitrogen.	Total phosphorus.	Total carbon.	Nitrate nitrogen.	Lime requirement.
Clover soil	4,088	2,390	48,200	8.0	3,000
Sudan grass soil	3,586	2,228	47,400	10.8	4,000
Prairie soil	4,538	2,208	53,800	7.1	2,000

It is very evident that the heavy feeding habit of the Sudan grass has depleted the soil of nitrogen and phosphorus and indirectly of carbon, likewise has increased the acidity over that of the adjacent clover soil. As neither of these plots had received an application of manure for three years previous to the time of sampling and no other fertilizers have ever been applied, the results may be taken as fairly conclusive. It is surprising, however, that the nitrate-nitrogen is higher in the Sudan grass soil than in the others. This fact may be explained by the biological processes which are discussed below.

The bacterial and mold content of these three soils, (Table 2) based on the average counts of twelve plates, shows almost three times the number of bacteria in the clover soil as in the Sudan grass

TABLE 2.— *Average number of bacteria and molds in field soils.*

	Thousands of organisms per gram air dry soil.			
	Cook's No. 2 medium.		Lipman and Brown's modified synthetic agar.	
	Bacteria.	Molds.	Bacteria.	Molds.
Clover soil	3,607	406	4,822	127
Sudan grass soil	1,395	507	1,523	127
Prairie soil	25	240	747	120

soil. The mold content of the two cultivated soils are approximately equal. Both of the soils show a decidedly higher flora, from the standpoint of numbers, either bacteria or fungi, than the virgin prairie soil. However, it is extremely difficult, if not impossible, to interpret the crop producing power of a soil by numbers of microorganisms alone.

It has been demonstrated by many workers that the physiological efficiency of the biological processes in soils as measured by their ammonifying, nitrifying and azofying powers, bears no relationship to the total number of microorganisms contained in them. It was not expected that these soils would prove exceptional cases, but it was expected that the Sudan grass in particular would have an influence on those soil microorganisms concerned in the transformation of nitrogen. That such was not the case, however, was shown by an analytical study of the changes in the nitrogen compounds of both organic and inorganic nitrogen carriers added to the soils, the results of which are shown on Tables 3, 4, and 5. The production of ammonia, (Table 3); the formation of nitrates, (Table 4); and the utilization of atmospheric nitrogen, (Table 5), plainly show the ammonifying and the azofying powers in each of these three soils to be about equal; but the nitrifying powers of the Sudan grass soil is decidedly marked. The prairie soil did not possess the power to

TABLE 3—*Ammonifying power of field soils.**

Soils.	Ammonia in soil.	Dried blood. Ave. mg. nitrogen ammonified less check.	Dried blood. Percent nitrogen added ammonified.	Cottonseed meal. Ave. mg. nitrogen ammonified less check.	Cottonseed meal. Percent nitrogen added ammonified.
Clover	4.34	78.17	11.2	173.16	48.7
Sudan grass	1.68	93.98	13.5	132.60	35.8
Prairie	2.38	72.29	10.3	138.83	39.1

* Determinations made on 100 gm. soil plus 5 gms. organic nitrogen incubated seven days at room temperature and optimum moisture.

TABLE 4.—*Nitrifying power of field soils.**

Soils.	Nitrates in soil.	0.1 gm. ammonium sulfate. Ave. mg. nitrogen nitrified less check.	0.1 gm. ammonium sulfate. Percent nitrogen added nitrified.	0.1 gm. dried blood. Ave. mg. nitrogen nitrified less check.	0.1 gm. dried blood. Percent nitrogen added nitrified.
Clover	1.6	trace	0.0	1.62	5.7
Sudan grass	4.5	1.62	7.6	5.10	18.2
Prairie	1.7	trace	0.0	0.0	0.0

* Determinations made on 100 gm. soil incubated with additions for four weeks at room temperature and optimum moisture.

TABLE 5.—*Azofying power of field soils.**

Soils.	Ave. mg. nitrogen found.	Ave. mg. nitrogen check.	Ave. mg. nitrogen fixed per gm. dextrose.
Clover	7.00	1.40	5.60
Sudan grass	7.21	1.40	5.81
Prairie	6.44	1.40	5.04

* 5 c. c. fresh soil infusion inoculated into 100 c. c. 1 percent Lipman and Brown dextrose solution, incubated 12 days at room temperature then kjeldahlized.

nitrify either ammonium sulfate or dried blood, and the clover soil showed little action on ammonium sulfate; but the nitrifying organisms in the Sudan grass soil had been stimulated evidently to such an extent that they were able to attack and nitrify both the organic and inorganic forms of nitrogen supplied. The latter action is possibly the explanation for the larger amounts of nitrates found in this soil in Table 1.

GREENHOUSE EXPERIMENTS.

The greenhouse tests were run to determine the effect of additions of various fertilizers on the ability of the soils from each of the three plots to produce crop growth, and also to determine the physiological efficiency of the microorganisms. The additions were made in amounts calculated on a two million pound acre basis to duplicate pots on each of the three soils, as follows:

Pots.	*Additions.*
1- 2	Nothing — check.
3- 4	Lime. Clover and Sudan grass soils 3 tons, prairie soil 1½ tons.
5- 6	Lime plus 8 tons manure.
7- 8	Lime plus manure plus 1,000 pounds raw rock phosphate.
9-10	Lime plus manure plus 200 pounds acid phosphate.
11-12	Lime plus manure plus 300 pounds 2-8-2 complete commercial fertilizer.

The pots were seeded to Marquis wheat on November 1, and, because of the necessity of finishing all determinations before a certain time, were harvested April 7, 1921, when the plants were at their maximum growth but before they had set seed.

Table 6 shows the green and dry weight of the wheat harvested from these plots. An examination of these data leaves no room to doubt the assertion that Sudan grass, in spite of its heavy feeding habits, does not materially injure the crop producing capacity of the soil, neither does it influence that soil in its favorable response to applications of materials commonly used as fertilizers. The check pots showed a better growth on the Sudan grass soils than on the clover soil but both slightly less than on the virgin soil. In the first

TABLE 6.— *Average weights and height of wheat harvested from potted soils.*

Pots.	Treatments.	Height, inches.	Green weight, grams.	Dry weight, grams.
	Clover Soil.			
1- 2	Check	20.5	22.4	6.7
3- 4	Lime	24.5	43.3	12.4
5- 6	Manure plus lime	23.0	42.1	12.0
7- 8	Raw rock phosphate plus manure plus lime	31.5	46.3	12.1
9-10	Acid phosphate plus manure plus lime.	26.5	44.0	12.5
11-12	Complete fertilizer plus manure plus lime	30.0	48.3	12.9
	Sudan grass soil.			
13-14	Check	25.0	37.6	9.5
15-16	Lime	28.5	50.9	14.2
17-18	Manure plus lime	30.0	50.3	12.6
19-20	Raw rock phosphate plus manure plus lime	25.0	46.6	12.6
21-22	Acid phosphate plus manure plus lime.	27.0	47.3	13.3
23-24	Complete fertilizer plus manure plus lime	31.0	51.7	14.2
	Prairie soil.			
25-26	Check	25.5	39.1	11.0
27-28	Lime	22.0	32.1	9.5
29-30	Manure plus lime	25.0	41.1	9.9
31-32	Raw rock phosphate plus manure plus lime	24.5	41.3	9.3
33-34	Acid phosphate plus manure plus lime.	26.5	45.3	11.4
35-36	Complete fertilizer plus manure plus lime	23.5	36.4	9.1

two cases the response was equally marked to applications of lime, or lime and manure, with or without combinations of phosphorus or complete commercial fertilizer. The virgin prairie soil, however, was apparently depressed in its crop producing powers by nearly all of the treatments. This may be explained by an examination of that portion of Table 7 which shows the nitrate content and of Table 4 showing the nitrifying efficiency of the three soils. It is hardly conceivable that the nitrate-forming organisms were entirely lacking as indicated in Table 4; it seems more probable that their action was so slow that their products were utilized by other microorganisms as fast as formed. In the case of the potted soils, the growing plants were competitors with the soil organisms. In other words, the vitality of the nitrate-formers was so low that they were unable to oxidize the large amount of ammonia formed to nitrates in sufficient amounts to produce a rate of growth equivalent to the other two soils, and this in spite of the fact that the prairie soils contained a larger amount of total nitrogen than either of the other two. Table 7 also shows that the nitrifying efficiency of the flora of the Sudan grass

TABLE 7.—*Average nitrate-nitrogen and total nitrogen content of potted soils at end of growing period.*

(Expressed in pounds per acre.)

Pots.	Treatments.	Total nitrogen. Original soil.	Total nitrogen. Potted soil.	Nitrate-nitrogen. Original soil.	Nitrate-nitrogen. Potted soil.
	Clover soil.				
1- 2	Check	4,088	3,894	8.0	10.6
3- 4	Lime	....	3,948	....	9.2
5- 6	Manure plus lime	....	3,836	....	10.0
7- 8	Raw rock phosphate plus manure plus lime	....	3,780	....	13.6
9-10	Acid phosphate plus manure plus lime	....	3,808	....	12.2
11-12	Complete fertilizer plus manure plus lime	....	3,836	....	19.0
	Sudan grass soil.				
13-14	Check	3,586	3,416	10.8	15.0
15-16	Lime	....	3,528	....	12.2
17-18	Manure plus lime	....	3,584	....	12.0
19-20	Raw rock phosphate plus manure plus lime	....	3,612	....	10.2
21-22	Acid phosphate plus manure plus lime	....	3,684	....	12.2
23-24	Complete fertilizer plus manure plus lime	....	3,668	....	10.8
	Prairie soil.				
25-26	Check	4,538	4,088	7.1	9.0
27-28	Lime	....	4,172	....	13.0
29-30	Manure plus lime	....	4,228	....	9.6
31-32	Raw rock phosphate plus manure plus lime	....	4,228	....	9.8
33-34	Acid phosphate plus manure plus lime	....	4,284	....	9.0
35-36	Complete fertilizer plus manure plus lime	....	4,200	....	9.8

soil, as measured by the amount of nitrates produced, is greater than that of either the clover or prairie soils, thus indicating that this crop may stimulate nitrification under cropped conditions. This conclusion is also supported by the results showing the high nitrifying efficiency of Sudan grass soil recorded in Table 4, and is further emphasized by the results gained from the bacteriological tests of the potted soils after the crop was removed. The result of these tests, shown in Table 8, indicate the ammonifying, nitrifying and azofying powers of the three soils as affected by the different treatments. As there was only a slight variation between the checks and the different treatments, the various powers of each soil are condensed. Each result therefore represents the average of 24 determinations.

TABLE 8.— *Physiological efficiency of potted soils.*

	Ave. mg. nitrogen as dried blood ammonified.	Ave. mg. nitrogen as ammonium sulfate nitrified.	Ave. mg. nitrogen per gram dextrose azofied.
Clover soil	117.2	13.7	7.6
Sudan grass soil	158.8	11.3	8.5
Prairie soil	154.1	10.8	8.9

These results are comparable with those shown in Tables 3, 4 and 5. It was expected that the various biological powers would be increased by the favorable greenhouse conditions, but the facts stand out clearly that, that while the heavy soil feeding Sudan grass may reduce the total bacterial content of the soil, it does not influence those that are concerned in the transformation and rendering soluble of the plant food and, more important still, it may even stimulate those concerned in the transformation of nitrogen.

CONCLUSIONS.

Sudan grass, in spite of its heavy feeding habits, does not materially reduce the crop-producing power of this soil, neither does it influence the soil in responding favorably to the application of common fertilizers.

Sudan grass lowers the total bacterial content of the soil on which it grows, but apparently does not interfere with the physiological activities of the microorganisms which are concerned in the production of available plant food.

The organisms concerned in the transformations of nitrogen in the soil are favorably influenced by the growing of Sudan grass. This effect is particularly noticeable in its effect on the following crops.

THE PRODUCTIVENESS OF SINGLE AND DOUBLE FIRST GENERATION CORN HYBRIDS.[1]

D. F. JONES.[2]

Investigations dealing with the effects of inbreeding and crossing have resulted in a large amount of data showing the yielding capacity of hybrids from inbred strains of corn and it is here proposed to bring together these figures and to show what value they may have for the application of inbreeding and crossing to corn improvement.

[1] Contribution from the Connecticut Agricultural Experiment Station, New Haven, Conn. Received for publication, January 1, 1922.

[2] Plant Breeder.

As outlined previously (7),[3] the main value of inbreeding a naturally cross-fertilized plant comes in the opportunity it affords of controlling the heredity thru the pollen parent as well as the seed parent. Obviously, the results to be expected from the application of selection in self-fertilized lines depends largely upon the amount of material worked with and the ability to find potentially high-yielding inbred strains. Thruout the experiments on inbreeding begun by Dr. E. M. East in 1905 and carried on subsequently by Dr. H. K. Hayes and later by the writer, relatively few plants have been self-pollinated and there has not been any direct attempt to secure exceptionally vigorous inbred strains. The aim was to find out first as much as possible in regard to the principles underlying the inbreeding problem. The plants were self-fertilized at random. No discrimination among the seed ears planted was made except in the case of the strains selected on the basis of chemical composition of the seed. In most cases only one progeny was grown in each line and the number of plants raised seldom exceeded twenty-five or thirty in any one family.

Now that the importance of basing selection in self-fertilized lines on as large amount of material as possible is realized, a new series of inbred strains has been started from locally-adapted and proved varieties, with the object of obtaining a high-yielding type of corn well suited to southern New England conditions. These are now in the fourth generation. As yet no crosses have been made between these selections and the hybrids reported here are all from the original inbred strains, some of which are now in their sixteenth year of consecutive self-fertilization.

All of the strains used in producing the hybrids had been inbred for at least five years previous to crossing and were all characteristically uniform and much reduced in size, vigor and productiveness. Most of these inbred strains have been described previously. The ones chiefly used in making the crosses were four lines from Leaming corn obtained originally from central Illinois. (3, 6.) Three lines came from Burr's White, a dent variety selected for high- and low-protein by the Illinois Agricultural Experiment Station and were further selected in the same direction in successive self-fertilized generations. Four other high-protein strains were selected from a local strain of Leaming, and three from a variety of flint corn known locally as Burwell's Yellow. These selected strains have been described previously (4). In addition to these, two other strains of flint and two of floury corn have entered into the parentage of some

[3] Reference by number is to "Literature Cited, p. 252.

of the crosses. The larger part of the yields are from various combinations of the inbred strains from Illinois Leaming not selected for any particular character, together with the selected protein strains from Connecticut Leaming and Illinois High- and Low-Protein.

The hybrids resulting the first year after crossing two inbred strains are called single crosses, to distinguish them from the so-called double crosses which represent the combination of four inbred strains brought together by crossing again two first generation hybrids. Most of the combinations were grown to furnish the data on the effects of crossing on the development of different parts of the plant and upon variability which have been previously reported (6). Some of them yielded very poorly and would never have been grown for yield alone. All the results on yield, some of which have been published before, are here brought together and compared with the results from a variety test which has been carried on for a number of years in cooperation with the Storrs Agricultural Experiment Station. Over one hundred and fifty different varieties of dent and flint corn from different parts of the state and adjoining regions have been tested and these probably include most of the highest-yielding kinds of corn grown in this region.

The crosses and the varieties were grown under similar conditions. They were planted at the same time, harvested when ripe and a sample taken from each plot to determine the amount of actual dry matter produced. The plots consisted of single rows containing from twenty-five to fifty hills and the yields are calculated from the weight of the corn on the cob over to bushels of shelled grain with 12 percent moisture per acre. The plots were duplicated in different parts of the field and the higher yielding varieties and crosses were usually triplicated. Varieties and crosses of the same size of growth and time of ripening were grouped together, in order to obviate some of the effect of competition between adjoining rows, altho in some cases the yields are probably somewhat distorted by the unequal growth of adjoining rows.

So many different hybrid combinations have been grown that it does not seem to be worth while to report all the yields individually. All that is attempted here is to compare the yielding power of the parental inbred strains and the two classes of hybrids with that of the best varieties grown in the state. For several reasons, it is difficult to make a fair comparison. Much of the inbred material used in making the crosses is out of varieties which came originally from Illinois. It has been grown and naturally selected for our conditions here for so many years that it is obviously impossible

to compare the crosses with their original parental varieties either in Connecticut or in Illinois. On the other hand to compare them with local varieties brings in many unknown factors. As a general rule, the highest yielding local varieties are more productive here than any varieties recently introduced from the western and southern corn growing districts, altho such corn will usually grow satisfactorily and in most seasons will mature fairly well.

All of the corn has been grown at Mt. Carmel which is about ten miles from Long Island Sound and is in the same biological zone as the central corn growing area. The Upper Austral zone (8) lies mainly in the states of Ohio, Indiana, Kentucky, Illinois, Missouri, Iowa, Kansas and Nebraska but it extends eastward at the low altitudes and includes Long Island and skirts the northern shore of Long Island Sound.

Seed of the Leaming corn, from which the inbred strains from Illinois were derived, was obtained from the original source and yielded at the rate of 75 bushels per acre in 1916 and 90 bushels per acre in 1918. In 1916, it was surpassed in productiveness by 20 local varieties, the highest yield of the latter being 95 bushels per acre and four local varieties outyielded it in 1918, the highest yield being 96 bushels. Other varieties from Illinois which have been tested are Funk's 90-Day and Sutton's Yellow Dent. In production of grain these varieties have not yielded as well here as the best local varieties.

The single and double crosses derived from the Leaming and Burr's White stock have matured in from 120 to 140 days from planting. Most of the highest yielding local varieties require the same amount of time to ripen properly. However, many of the varieties included in the variety test matured from 10 to 20 days earlier. The crosses between the Connecticut Leaming strains and between the flint strains required about the same length of time. On the whole, many of the varieties matured earlier than the crosses and hence are somewhat handicapped in a comparison on the basis of yield, as it is a general rule that the longer a corn plant grows the more it yields provided it matures properly. For this reason, and because different numbers of crosses and varieties were grown, the figures for yield given in Table 1 must be studied with considerable caution.

The results are given in the form of frequency distributions, divided into classes of ten bushels difference in yield. For the reasons given above, the averages for each group mean very little. Attention is called particularly to the distribution of the yields.

From this it is believed possible to derive fairly reliable conclusions. Each entry in Table 1 is the actual yield of a single plot calculated to bushels per acre. Each replicated plot appears separately as the yields of different rows of the same variety or cross are not averaged. Check plots were grown in every fifth row, but the yields given in Table 1 are not corrected to the check rows as they are in Tables 2 and 3. The reason for this is that, in all the years of the test except the first, one single or one double cross was used to plant the control plots. The comparison of the yields of these check rows with the varieties growing in adjoining rows which is made in the frequency distributions shown in Table 1 gives the most convincing evidence of the value of corn hybrids.

The inbred strains after being reduced to uniformity and constancy have yielded, in the four years, from 5 to 65 bushels per acre and have averaged altogether from 20 to 35 bushels. This is from one-half to one-third of the yield of normal plants under the same conditions. Of the eighteen different inbred strains grown, nine have been selected for high protein and for this reason are expected to be somewhat lower in yield than strains not so selected. The one inbred strain selected for low protein has been a consistently good yielder. One of the Illinois Leaming strains has given the best results on the whole, of any of the inbred strains. The plants are sturdy growers, stand up well in the field when others are blown down, and their foliage is dark green in color and free from the mottling and flecking during the later part of the season which is a conspicuous weakness of many inbred strains. The plants are appreciably less subject to smut parasitism in Connecticut (5) and the ears are seldom moldy.

But, even at its best, this strain does not compare with the original variety in productiveness. Many of the inbred strains, particularly the high-yielding ones, are notably deficient in pollen production. Some are very nearly sterile, particularly during exceptionally dry or extremely hot weather. The yields reported here were made possible by pollen from other plants in the same field. When these plants are grown in isolated fields and are dependent upon their own pollen or that from other inbred strains their production of grain is usually considerably reduced.

The poor production of inbred plants is one of the chief handicaps in utilizing crosses of inbred strains. There is a good reason to expect that when corn is extensively selected in self-fertilized lines that much better inbred plants can be secured. It is important to keep the pollen production sufficiently high to insure a full setting

of seed in open pollination. Our experience shows that the results obtained with hand pollination are not always a reliable guide as to what the plants will do in the open field.

The next point to be considered is the yielding ability of first generation crosses between these inbred strains. Such crosses were first grown in 1908 and reported by East (1). More extensive data from some of the same strains further inbred and the crosses grown in 1909 and 1911 were given by East and Hayes (2). A few crosses were also grown in 1913 but not reported. In 1916 and 1917 an extensive series of crosses between many of these same strains still further inbred were grown by the writer (6). The yields from these are included in the data given here. While there is no exact way of comparing the results of one season with another there is no indication that crosses between strains inbred for 10 generations or more are more or less productive than the same crosses made earlier.

Noll (9) reports a series of first generation crosses between strains inbred from two to four years. The yields of the hybrids are compared with those obtained from the original variety. While some of the crosses exceeded the variety in yield, no marked superiority was obtained. These results agree in general with the data given here. During the four years tested, in only one year, 1919, did the combinations of two inbred strains, or single crosses as they are called, clearly outyield the varieties grown under the same conditions. In 1918, only four single crosses were grown and these can be left out of consideration. In 1919 however, many single crosses surpassed the highest yielding varieties with a wide margin and the distribution of the yields shows the superiority of the crosses. In the other three years, no advantage was derived from the single crosses as compared to the varieties.

In 1917, crosses of several varieties with one inbred strain (the best one so far found) as the pollen parent were grown and their yields are included in Table 1. These are of some interest as they compare with the grading-up practice in animal breeding where a pure bred sire is used with grade stock. The yields averaged about 10 per cent better than the varieties taken all together.

When the inbred strains were reduced to their low level of vigor after five or more generations of self-fertilization it was noticed that the first generation hybrids produced from such strains were handicapped at the beginning of the season. The seedlings were smaller in size and slower in growth at the start. Growth curves (6) show that such plants do not attain their maximum rate of development

until about the middle of the season. The hybrid seeds are borne upon weak inbred plants and for that reason are much smaller in size and have less stored food for the young plants to start on than the large variety seeds grown on vigorous plants. This is a serious obstacle in the way of utilizing first generation hybrids.

It is possible to overcome this handicap and still retain hybrid vigor at its maximum by crossing again two first generation hybrids. The plants then start from large well-nourished seeds produced on strong, vigorous plants; the seeds germinate more completely; the seedlings start more quickly and grow more rapidly from the start. Such a double cross differs widely in genetic construction from a single cross. In the latter all plants are exactly alike in their hereditary composition if their parental inbred strains have been reduced to complete uniformity and constancy. In a double cross, however, the plants are all genetically unlike to a greater or lesser degree; but individually they are all essentially first generation hybrids. Recombination allowing recessive weaknesses to appear is not possible and, from the standpoint of even size of plant and uniform production of ears, double crossed plants are equal to their single crossed parents and in vigor of growth and productiveness are clearly superior, as shown in Table 1.

Another advantage may be possessed by the double crosses in that being somewhat more variable they may be more adaptable to different seasonal conditions. All the plants of a single cross developing at the same time may be affected by unfavorable weather conditions at a critical time and in some seasons may be unduly injured, whereas in the case of the double cross, part of the plants may escape injury.

Whatever may be the explanation of the increased yields the results of three years tests show unmistakably that the double crosses have a decided advantage over both single crosses and varieties. In 1918, the first year any double crosses were grown, ninety-four plots, containing many different quadruple combinations of the inbred strains previously described, ranged in yield from 55 to 135 bushels per acre. Grown in the same field, one hundred and sixty-five variety plots yielded from 45 to 115 bushels per acre. The lower range in the variety yields can not be compared with the double crosses because some of the varieties matured earlier. But disregarding the lower yielding half of the distribution the remaining figures which represent varieties which matured as late or later than any of the crosses, fall far short of the results given by the hybrids. The mode of the latter is at 115 which is the upper limit of the distribution of the variety yields.

TABLE 1.—*A comparison in yield of inbred strains of corn and their single and double first generation hybrids with normally pollinated varieties.*

Class.	Year grown.	Bushels of shelled corn with 12 percent moisture per acre. 5	15	25	35	45	55	65	75	85	95	105	115	125	135	Number of strains.	Average yield.
Inbred strains	1916	11	23	14	12	4	..	..	..	..	..	...	...	...	...	64	21.1±1.0
Single crosses	1916	1	1	5	6	12	11	9	19	21	12	6	2	...	...	105	69.5±1.6
Varieties	1916	..	..	..	5	11	44	44	32	34	25	3	...	...	...	198	70.4± .8
Inbred strains	1917	..	1	9	8	10	3	..	..	..	..	...	...	...	...	31	36.6±1.4
Single crosses	1917	..	..	..	..	..	..	4	7	11	14	8	5	...	...	49	91.1±1.3
Varieties	1917	..	..	..	..	..	1	6	19	18	28	4	1	1	...	78	86.2± .9
Varieties × inbred	1917	..	..	..	..	..	..	..	1	7	7	6	1	...	...	22	94.5±1.4
Inbred strains	1918	..	1	8	5	2	4	1	..	..	..	...	...	...	...	21	36.4±2.0
Single crosses	1918	..	..	..	..	..	..	..	1	0	2	0	1	...	...	4	95.0
Double crosses	1918	..	..	..	..	..	1	3	6	12	13	23	24	9	3	94	102.8±1.2
Varieties	1918	..	..	..	..	1	22	44	41	31	21	4	1	...	...	165	74.9± .7
Inbred strains	1919	1	3	10	4	5	3	..	..	..	..	...	...	...	...	26	31.9±1.7
Single crosses	1919	..	..	..	1	1	4	9	15	29	6	1	...	...	...	66	78.0±1.0
Double crosses	1919	..	..	..	..	1	7	13	27	13	3	2	...	...	...	66	74.2±1.0
Varieties	1919	..	..	1	7	17	48	38	12	4	..	...	...	...	...	127	58.1± .7
Single crosses	1920	..	..	1	8	11	8	3	..	..	..	...	...	...	...	31	46.3±1.2
Double crosses	1920	..	..	8	25	45	64	45	30	1	..	...	...	...	...	218	54.5± .6
Varieties	1920	..	..	9	33	35	25	8	3	..	..	...	...	...	...	113	44.9± .7

The same higher distribution of the yields of the double crosses is seen in the results for 1919 and again but not so pronouncedly in 1920. In the last year all yields are low. Probably the fairest comparison that can be made is to consider the yields of the ten most productive double crosses with the ten highest yielding varieties during the three years as shown in Table 2. Here it will be noted that the lowest of the ten crosses is higher than the highest yielding variety, except in 1918 where there is a difference of only

TABLE 2.— *The ten highest yielding double crosses compared with the ten highest yielding varieties during three years trial.*

(Expressed as bushels per acre.)

1918		1919		1920	
Double crosses.	Varieties.	Double crosses.	Varieties.	Double crosses.	Varieties.
117	96	96	79	84	59
116	93	94	79	76	57
109	92	93	75	76	57
109	92	91	75	74	55
105	89	91	72	74	55
101	89	90	71	72	54
99	86	88	71	71	53
99	86	88	67	70	52
97	86	88	67	70	51
93	85	85	64	69	51
104.5	89.4	90.4	72.0	73.6	54.4
Increase from double crosses.					
15.1 bu. per a.		18.4 bu. per a.		19.2 bu. per a.	
16.9 percent		25.6 percent		35.3 percent	

TABLE 3.— *The average yield of one double cross compared with the yields of two high producing varieties during three years.*

Class.	1918 Yield.	1918 No. plots.	1919 Yield.	1919 No. plots.	1920 Yield.	1920 No. plots.
Double crossed Burr-Leaming........	116	31	88	3	55	71
Highest yielding flint variety in 1918...	96	4	54	2	51	2
Highest yielding dent variety in 1918..	92	4	58	2	39	2

TABLE 4.— *Number of moldy ears shown by flint and dent varieties, single and double crosses and inbred strains as grown in 1919.*

Class.	Percent of moldy ears. 2	7	12	17	22	27	32	37	42	47	52	57	62	Number of strains	Average percent.
Flint varieties..	2	14	16	17	8	1	2	2	1	1	0	0	1	65	16.54± .89
Dent varieties.	12	27	15	1	1	..	..	..	..	..	..	..	..	56	7.71± .38
Single crosses..	23	18	7	3	0	0	1	..	..	..	..	..	..	52	6.52± .53
Double crosses.	22	11	9	2	2	..	..	..	..	..	..	..	..	46	6.67± .55
Inbred strains*	11	5	1	1	1	0	0	1	..	..	..	..	..	20	7.25±1.32

*One strain had all the ears slightly molded.

three bushels. The average increases of 16.9, 25.6 and 35.3 percent are certainly significant. N ... ilts as a whole noticeably in favor ... pared with the varieties but particular combinations showed up well in each of the three years tested. In 1918, a quadruple combination of two inbred strains from Illinois High- and Low-Protein out of Burr's White with two inbred strains from Illinois Leaming was grown as a check thruout the variety plots. For convenience this particular combination has been called Double Crossed Burr-Leaming. These thirty-one check plots in all averaged 116.3 bushels. A slightly different combination, in which one inbred strain from Connecticut Leaming was substituted in place of one of the Burr White strains, was grown in twenty-six plots and these averaged 109.3 bushels. The highest yielding dent variety gave 92.3 bushels per acre and the highest flint 96.4 the same year, these variety yields being an average of four plots each.

In 1919, the same double crossed Burr-Leaming yielded 88.1 bushels. The highest dent variety produced 79.1 and the highest flint 79.0. These yields are based on an average of two plots for each of the varieties and three plots for the double cross. In 1920, the double crossed Burr-Leaming was again used as control and 71 plots in all averaged 54.8 bushels. This average yield was equalled or slightly exceeded by four varieties, two dents giving 54.8 and 56.6 and two flints giving 56.9 and 59.4. The variety yields represent an average of two plots each and have been corrected for soil differences by adding or subtracting the deviation in actual yield from the theoretical yield of the control, as calculated from the two adjacent check plots, to the average yield of all the check plots. The yields given above can therefore be compared fairly with each other with the reservation that the small number of plots of the varieties makes their results somewhat less reliable than that obtained from the large number of plots of the double cross.

In 1920, one double cross representing a new combination of two inbred flint with two inbred dent strains yielded 84.3 bushels which is 42 percent higher than the highest yielding variety grown that year. Moreover, twenty-four different double crosses, not counting check plots, yielded more than the highest yielding variety. In this comparison all yields are an average of two plots and have been corrected to the controls.

One other comparison remains to be made. From a consideration of the behavior of certain crosses and varieties thruout the three years, as shown in Table 3, it is evident that the yields of particular

crosses fluctuate from year to year in the same way as do individual varieties. The same relative position is held, however, during the three years. From the practical standpoint this is the most important comparison that can be made.

Examined in all possible ways, the results clearly indicate a superior yielding ability possessed by the double crosses. It would be more satisfactory if the inbred strains had all been derived from local varieties and only these varieties had been compared with the crosses. Since this was impossible it seemed to be the best plan to place all the crosses in competition with all the varieties grown. This is the test which all corn must meet before its actual value can be demonstrated.

In addition to the larger yields there has been an appreciable improvement in quality in many of the hybrids due to less moldy corn, fewer immature and poorly developed ears. Table 4 gives the results obtained in 1919 which, being very wet in the fall, was favorable for mold to develop. No significant differences are shown in the averages of all the plots between the crosses and the dent varieties, but the distributions of the data show that more of the crosses are in the class of lowest percent of mold. None of the varieties were entirely free from moldy corn whereas eight inbred strains, five single crosses and one double cross were. Most of the double crosses had certain inbred strains in their make-up which were notably subject to mold damage. Other crosses are noticeably free from injury. In 1918 the double crossed Burr-Leaming combination gave only two slightly moldy ears in the crop from more than 3,000 plants.

It is also expected that a real resistance to smut infection can be obtained together with high yield. Unfortunately many of our otherwise good inbred strains are badly affected by smut parasitism. The double crossed Burr-Leaming has two inbred parents which are regularly severely injured by smut, one showing as high as 73 percent of the plants attacked, during the past season. Contrasted with this is the fact that these same strains are notably free from external indications of root-rot infection. The plants stand upright thruout the season and their foliage stays green until the seeds are well ripened. The husks are quite green when the seeds are glazed and the ears are as a rule free from mold.

Even tho inbred strains when crossed do yield more than other kinds of corn it yet remains to be demonstrated that hybrid seed can be produced in sufficient quantity and at a low enough cost to be an important factor in corn growing. The most serious obstacle

in the way is the [illegible] ntal types so far obtained, when these [illegible] ery effort should be made to find as high yielding inbred strains as is possible to secure and it may be questioned whether or not weak strains, even tho they give good results when crossed in particular combinations, should be saved for the purpose of producing hybrid seed. The value of such weak strains may be realized in some other way, as, for example, by crossing with other strains and again selecting or by entering into the composition of a new variety which has been purified by inbreeding. But effort should be directed toward obtaining inbred strains which are themselves vigorous and productive. With these secured the attainment of high yielding, high quality, dependable types of corn, adapted to particular places and purposes and possessing a measure of freedom from several diseases which now seriously injure corn, will be in sight.

LITERATURE CITED.

1. EAST, E. M. The distinction between development and heredity in inbreeding. *In* Amer. Naturalist, v. 43: 173–181. 1909.
2. EAST, E. M. and HAYES, H. K. Heterozygosis in evolution and in plant breeding. U. S. Dept. Agric., Bur. Plant Ind., Bul. 243. 1912.
3. ————, and JONES, D. F. Inbreeding and outbreeding: their genetic and sociological significance. 285 pp. Philadelphia; Lippincott Co. 1919.
4. ————, and JONES, D. F. Genetic studies on the protein content of maize. *In* Genetics, v. 5: 543–610. 1920.
5. JONES, D. F. Segregation of susceptibility to parasitism in maize. *In* Amer. Jour. Bot., v. 5: 295–300. 1918.
6. ————. The effects of inbreeding and crossbreeding upon development. Conn. Agr. Exp. Stat. Bul. 207. 1918.
7. ————, Selection in self-fertilized lines as the basis for corn improvement. *In* Jour. Amer. Soc. Agron., v. 12: 77–100. 1920.
8. Merriam, C. H. et al. Fourth provisional zone map of North American. U. S. Biological Survey, 1910.
9. Noll, C. F. Experiments with corn. Penn. Agr. Exp. Sta. Bul. 139. 1916.

AGRONOMIC AFFAIRS.

ACTIONS OF THE ADVISORY BOARD OF THE AMERICAN SOCIETY OF AGRONOMY TO THE NATIONAL RESEARCH COUNCIL.

At a meeting of the Advisory Board of the American Society of Agronomy held with the Chairman of the Division of Biology and Agriculture, Dr. L. R. Jones, at the National Research Council, December 10, 1921, to adjust matters in reference to the relation of the Advisory Board to the Research Council and particularly with the idea of taking over certain agronomic projects which developed

within the Research Council during the war period, Messrs. Lipman, Marbut, and Piper, of the Board, present, and Prof. A. G. McCall in consultation, the following actions were taken:

I.

The Advisory Board established four committees, of three members each, as follows:

a. Committee on Soils, to consist of

Dr. C. F. Marbut, Bureau of Soils, Washington, D. C.
Dr. F. J. Alway, College of Agriculture, St. Paul, Minn.
Prof. S. D. Conner, Purdue University, La Fayette, Ind.

b. Committee on Fertilizers, to consist of

Dr. J. G. Lipman, College of Agriculture, New Brunswick, N. J.
Dr. F. E. Bear, College of Agriculture, Columbus, Ohio.
Dr. B. L. Hartwell, Agricultural Experiment Station, Kingston, R. I.

c. Committee on Crops, to consist of

Prof. C. V. Piper, Bureau of Plant Industry, Washington, D. C.
Prof. C. A. Mooers, College of Agriculture, Knoxville, Tenn.
Dr. C. A. Zavitz, College of Agriculture, Guelph, Ontario.

d. Committee on Plant Nutrition, to consist of

Dr. A. G. McCall, College of Agriculture, College Park, Md.
Dr. H. L. Shantz, Bureau of Plant Industry, Washington, D. C.
Dr. Robert Stewart, College of Agriculture, Reno, Nevada.

It is the idea of the Advisory Board that each of these committees shall consider and recommend on all projects coming within its province.

II.

Each line of investigation recommended by the Board and adopted by the Research Council shall be called a *project*, to each of which shall be designated a *project-leader*. Including the war projects of the Division of Biology and Agriculture, and which have now been put under the direction of the Advisory Board, the projects now before the Research Council are as follows:

a. Assistance in financing the publication of the Journal of the American Society of Agronomy; under direct supervison of the Board.

b. Better coordination and cooperation in agronomic research; under the supervision of the Board.

c. Soil Research Institute; project leader, Dr. J. G. Lipman.

d. Monograph on lime; project leader, Dr. W. H. McIntire.

e. Monograph on history of soil development; project leader, Dr. C. F. Marbut.

f. Physiological soil requirements of plants; project leader, Dr. A. G. McCall.

g. Pasture investigations; under charge of the Committee on Crops.

III.

In connection with the above scheme of organization, the following resolutions were passed:

a. That the Advisory Board of the American Society of Agronomy accepts the sponsorship of the agronomy projects of the Research Council instituted during the war, and also the personnel of the existing committees, with the exception that the Committee on Fertilizers is reduced to three members.

b. In accordance with the new scheme of organization, the project leader for each project is to be approved by the Advisory Board on nominations presented by the committee directly concerned with the project. Associates on each project are nominated by the project leader, subject to approval by the responsible committee and the Advisory Board.

TEXAS BRANCH OF THE AMERICAN SOCIETY OF AGRONOMY

Members of the Society who live within easy access of each other, and are therefore able to unite in a similar enterprise, may be interested in the following statement with reference to the recently-organized Texas Branch of the Society, which has been received from J. H. McDonald, the Secretary-Treasurer of the Branch:

"As you requested in your recent letter, I am sending you a list of the members of the Texas Branch of the American Society of Agronomy. They are as follows:

Local Members

T. Hensarling, *President*	E. W. Handley
W. P. Patton, *Vice-President*	C. C. Jobson
J. H. McDonald, *Secretary-Treasurer*	B. J. Masuda
U. E. Christopher	J. C. Miller
J. C. Graham	C. Real
H. Govea	

Honorary Members

J. O. Morgan	A. B. Conner
C. A. Wood	E. B. Reynolds
E. P. Humbert	B. Youngblood
J. H. Stallings	A. H. Leidigh
D. G. Sturkie	E. W. Geyer
W. H. Corpening	A. K. Short

"Our society meets twice per month. It is the general plan to have on each program one outside speaker, and two or three student speeches. The outside speakers include the College professors, the Experiment Station and Extension Service men. Programs of special excellence have been held lately. Doctor E. P. Humbert, professor and plant breeder of wide experience, recently addressed the club on Commercial Plant Breeding. Doctor Tanquary of the Experiment Station spoke on Beekeeping in Texas.

"As can be seen from what I have said, we have rather diversified programs, thereby insuring greater interest.

"The Club recently voted favorably on the establishment of a National Grain Judging contest. Plans for an inspection trip are now being discussed. The purpose of such a trip would be to visit big commercial seed farms, some agricultural sub-stations, and successful farms. We believe that such a trip would be of great help to prospective farm managers, etc."

WESTERN AGRONOMIC CONFERENCE

The sixth annual conference of agronomists in the eleven western states was held at Pullman, Wash., and Moscow, Idaho, July 20 to 22, 1922. The programs on Thursday afternoon and Friday morning were presented at Washington State College and those on Friday afternoon and Saturday at the University of Idaho. Inspection of the agronomic experiments on the Washington and Idaho stations and an 80-mile automobile trip from Moscow to Lewiston, Idaho. and return, were a part of the program. The Lewiston trip covered 30 miles of wide-spreading wheat fields in the rich Palouse district and the wonderfully scenic 10-mile descent into the canyon of the Clearwater and Snake rivers, with its panorama of orchards and farm lands.

The attendance included representatives from six states and of the U. S. Department of Agriculture, the usual number present at the meetings being about 40. The program consisted of the papers named below. Most of the papers were followed by spirited discussion.

"Water Requirements as Influenced by Tillage Methods" by D. E. Stephens, Sherman Co. Branch Station, Moro, Ore. Discussion led by F. J. Sievers, of the Washington station.

"A New Method of Mechanical Analysis and its Application to the Study of Soil Structure" by M. D. Thomas, of the Utah station.

"Results of Different Crop Residues on Organic Matter Maintenance in the Soil" by Henry Holtz, of the Washington station.

"Control of Morning Glory in Cultivated Lands" by George Stewart of the Utah station (read by M. D. Thomas).

"Control of Smut by Copper Carbonate." Discussion by B. F. Dana of the Washington station and C. W. Hungerford of the Idaho station.

"The Place of Hybridization in Crop Improvement" by E. F. Gaines, of the Washington station. Discussion led by J. A. Clark of the U. S. Department of Agriculture.

"Sunflower Studies in Montana" by H. R. Sumner, of the Montana station (read by Clyde McKee). Discussion led by R. K. Bonnett, of the Idaho station.

"Dry-Land Forage Crops" by H. W. Hulbert, of the Idaho station. Discussion led by R. O. Westley, of the Washington station.

"Pasture under Irrigation" by Clyde McKee, of the Montana station.

"Standardization and Certification" by C. B. Ahlson, Idaho State Seed Commissioner. Discussion led by C. W. Warburton, U. S. Dept. of Agriculture.

"Response in Crop Plants to Environmental Conditions" by H. M. Wanser, of the Adams County Branch Station, Lind, Wash.

"How Does the 'Suggested Outline for Lectures in a Standard Introductory Course in Field Crops' Meet the Needs of the Western States?" by E. G. Schafer, of the Washington station.

The program also included informal talks by President Upham of the University of Idaho, Dean Johnson of the Washington college of agriculture, and Dean Iddings of the Idaho college. The committee to arrange for the next annual meeting, which is to be held at Bozeman, Mont., consists of Clyde McKee of the Montana station, E. G. Schafer of the Washington station, and C. W. Warburton of the U. S. Dept. of Agriculture.

NOTES AND NEWS

Dr. Eugene Davenport retired on September 1st, after thirty-seven years of service as Dean of the College of Agriculture and Director of the Agricultural Experiment Station at the University of Illinois; and Professor Herbert W. Mumford, who has been for more than twenty years the Chief of the Department of Animal Husbandry at Illinois, has been appointed as his successor.

Dr. Edward C. Elliot, formerly Chancellor of the University of Montana, has been appointed President of Purdue University, at Lafayette, Indiana.

Henry Dunleavy has transferred from Allen farm, Texas, to Robstown, Texas, where he will be in charge of cotton breeding for a commercial grower of Mebane cotton seed.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 OCTOBER, 1922 No. 7

PLOT COMPETITION WITH POTATOES.[1]

B. A. BROWN.[2]

That there is much competition between adjacent plots in experimental work with many crops is an undisputed fact and considerable information has been published on this subject.

At the Storrs Station, competition between variety plots of soybeans and oats has been noted and a brief summary of the data is given here. In 1917, 25 single row check plots of soybeans averaged 26.9 bushels of seed per acre. The variety used as a check was a small, early-maturing one. When the check variety occurred between the varieties O'Kute and Swan or Mammoth Yellow and Mongol, all of which are much larger and later than the check, the latter averaged only 17.1 bushels of seed per acre or 63.6 percent as much as the average for all check plots. In the same series of plots were planted a few varieties of field beans, which were much less vigorous in growth than the soybeans and which matured 17 days before the check variety. The average for the four check plots of soybeans which were between two plots of filed beans was 38.4 bushels of seed per acre, or 142.7 percent of the average for all checks.

In 1919, a series of oat varieties were drilled solidly in 4 row (28 inch) plots, and the two outside rows of each plot were discarded at harvest. To obtain some measure as to the comparative yields of outside rows and the average of the two central rows, 10 outside rows from different plots were threshed and the grain and straw weighed. Although varying in the amount of increase, the outside rows averaged 73.2 bushels of grain and 3,802 pounds of straw as compared to 52.3 bushels of grain and 2,464 pounds of straw per acre for the average of the two central rows for the same 10 plots, or a 40 percent increase of grain and a 54.3 percent increase of straw.

[1] Published with the permission of the Director, Storrs Agricultural Experiment Station, Storrs, Conn. Received for publication, January 17, 1922.

[2] Assistant Agronomist.

Confronted with data from many stations with other crops and the results given above, the question arose whether there is competition between potatoes in the single row plots, 103.7 feet in length, which are used at Storrs for variety and strain testing. In these experiments, all potations have been planted with an Iron Age 2-man planter, set to drop seed pieces 12 inches apart, with rows 3 feet apart. A good stand of plants has been the rule. The fertilizer (4-8-4) has been applied through the planter at 1,500-2,000 pounds per acre, but always the same amount for the entire series of plots in any one year. "Medium ridge" cultivation and good spraying have been given.

Beginning in 1916 and through 1921, the same strain of Green Mountains has been used for the checks, which occurred every fifth plot, except in 1921, when they were every tenth plot. From the results of the six years, all the check plots, which had adjacent plots on either side with available yields were taken for this study. There were 137 such plots.

Although the natural producing ability of the soil varied considerably, it seems reasonable to suppose that plots on either side of the check would have practically the same conditions. Therefore, to find if the checks benefited by being between low yielding adjacent plots, the yield of each check was compared to the average yield of its two adjacents. If the checks did benefit by being between low yielding adjacents, than a negative correlation should result. However, a positive correlation of 0.271 ± 0.053 was found, which, while not enough greater than the error to warrant the conclusion that the yields of the checks increased with an increase of the yields of the adjacents, surely does not give any evidence of the reverse being true.

The conclusion is, therefore, that with conditions as stated above, yields of potatoes are not influenced by competition between single row plots.

AN INDEX FOR MEASURING THE PERFORMANCE OF WHEAT VARIETIES AND STRAINS.[1]

W. B. Kemp.[2]

Agricultural experiment stations are frequently confronted with the problem of measuring the progress that has been made in variety testing, selection, or breeding of wheat and other small grains. This is comparatively easy, as long as a large group of older varieties

[1] Contribution from the Maryland Agricultural Experiment Station, College Park, Md. Received for publication March 3, 1922.

[2] Associate Agronomist.

is retained without change for use as seed, because a new variety may always be compared with the average of the group. However, during many years of testing some of the older varieties are replaced by newer and apparently better ones; therefore, it is frequently difficult to make up such a group.

Experiment stations generally use check plots with which to compare the different varieties that are on test in any one year, but unfortunately they are not a reliable measure of changes that take place from one year to the next. This is true even when the same variety is used as check throughout a series of years. To illustrate this fact, the behavior of Currell's prolific and Fultz wheats are compared. The former was the check variety at the Maryland Station in 1889 and 1890; the latter has been used from 1891 to the present time. Table I shows a comparison of the yields of these two varieties together with the ratio of their yields.

TABLE I.— *Comparative yields of two varieties of wheats used as checks.*

	1891–'96	1897–1907	1908–'17	1918–'21
Fultz	36.6	30.9	25.15	17.33
Currell's	35.5	34.4	28.14	20.59
Ratio of Currell's to Fultz	0.970	1.113	1.158	1.190

The significant fact brought out by these figures is that although Fultz outyielded Currell's in the early years of testing, later Currell's outyielded Fultz and continued to increase in superiority. For some years, the Currell's variety was subjected to much mass selection and this, with the later gradual reestablishment of equilibrium, may account for the improvement in this variety. Or, Fultz may do relatively better when yields are high, as they were when wheat followed cowpeas, for the higher production of all varieties in earlier years may be accounted for by differences in the rotation. Then wheat generally followed cowpeas; later it frequently followed wheat, while now it always follows corn — a custom that was adopted because the greater proportion of Maryland wheat is planted on corn stubble.

Another peculiarity that makes it difficult to use a single variety as a basis for comparisons is illustrated by the behavior of Fultz, mammoth red, and China for the fourteen years since the last two were put on test. A study of the comparative yields of these varieties for the different years during this period shows that in years when the average wheat yields on the station plots ranged from 16 to 22 bushels per acre, Mammoth Red yielded 25.67 bushels, or 131.7 percent of average; China, 22.45, or 114.7 percent; and Fultz, 16.37, or 83.4 percent. But in years when average yields

ranged from 22 to 34 bushels, Mammoth Red averaged 29.20, or 104.2 percent; China, 30.93, or 111.4 percent; and Fultz, 27.46, or 99.4 percent. Or expressed in another way; in unfavorable wheat years when average varieties yielded 8.17 bushels less than the average for the entire period, Mammoth Red fell below the average by 3.53 bushels; China by 8.48; and Fultz by 11.09. In unfavorable years, Mammoth Red was much less affected and Fultz much more so than are average varieties; while China showed just about the average diminution in yield. It is evident that China would more nearly fulfill the requirements for a check variety than would either of the others; but as a measuring stick, even it leaves much to be desired.

In an effort to establish an index that will measure the progress from year to year, it immediately becomes apparent that consideration of the average behavior of as many varieties as possible is necessary before the environmental effect between any two successive years can be measured. Thus, if 35 varieties are put on test, of which 30 are carried for two or more years and 5 are replaced by new ones the second year, and if the 30 original varieties make an average yield of 20 bushels per acre in one year and 25 bushels in the following year, this difference of 5 bushels or of 25 percent must be corrected before any change can be recorded for the test as a whole. If in the first year, the average yield of all 35 varieties on test was 19 bushels and in the second year 26, the change in yield brought about by the substitution of the 5 varieties may be found by using the following proportion — 20 (the yield during the first year of the 30 varieties on test both years) : 19 (the yield of all 35 varieties) :: 25 (the yield of the same 30 varieties in the second year) : (the yield that all 35 varieties would have produced in the second year if they had been continued). By calculation this would be found to be 23.75. But the actual yield in the second year was 26.0 bushels. The substitution of the 5 new varieties, therefore, caused an increase in average yield of 2.25 bushels — a figure that should be correct except for variation in seasonal response of different varieties, and these variations should tend to counteract each other. The 23.75 bushels is the base from which the index of any variety for that year is calculated and is given a value of 100. The 26 bushel yield would thus have a value of 109.5. This is calculated as follows: 23.75:26::100:109.5. Taking similar data from table 2 for the years 1913 and 1914, the following results are obtained, 22.32:34.27::19.57:X or 34.04. 30.04:33.56:: 100 : 112.

The size of the base for any particular series of tests depends upon the group of varieties that by chance or design were included in the first year's trial. Therefore, the index for one series does not necessarily bear any relation to that for another, unless the other series had the same varieties on test in its first year. But the ratio between different series of indices is always comparable. If any one variety has remained on test for a number of years its average index for different periods should, on the whole, remain constant, except where cyclic seasonal conditions have produced cyclic responses.

To determine the validity of an index established as above, separate averages were obtained for the first and second halves ot its test period for each variety that remained on trial for eight or more years. These averages brought out the fact that the index for most varieties had a tendency to slowly rise. A small cumulative error could cause such a result, and two of these were finally located. A study of the indices of eighty-seven varieties that had not been dropped until they had been on test for three or more years showed that they came in at 145.9, but in their second year made only 143.9. The tendency to drop, after one year, those varieties with very low yields had eliminated the lowermost varieties of a normal frequency distribution, and had advanced the mean by two points. The eighty-seven varieties were dropped from test on an average index of 145.2; although in the year before their last they had scored 150.9. This fact revealed a tendency to drop a variety after a very poor year for that variety, instead of dropping it after a normal year. An error of 5.7 resulted from this tendency. Both of these errors were eliminated by removing from consideration any variety that was carried for less than three years, and figures for the first and last years were dropped from all varieties that were used to establish the final index.

The present figure shows no tendency for average varieties to either advance or decline, but there are a few varities whose index is apparently advancing, while that for others is becoming smaller. A plausible theory to account for these variations assumes that by crossing or mutation a biotype has appeared within the variety and is gradually gaining the ascendency. Or, perhaps, one already present in a variety new to the section is favorably affected by its change of residence. If this biotype is an inferior one, with small seed or with an overtopping growth, a descending index will result. In most cases, however, only a superior one can gain the ascendency, and with its gain will come an ascending index.

TABLE 2.—*Indices for thirty years of wheat variety tests at College Park, Maryland.*

1	2	3	4	5	6	7	8	9	10	11
Year.	Varieties on test.		Varieties from former years.		Varieties in following year.		Yield if all on test were the twelve of 1890.	Index for all on test.	Index for	
	Number.	Yield.	Number.	Yield.	Number.	Yield.			Fultz.	Mammoth Red.
1890	44	10.80	......	....	12	13.01	13.01	83	....	....
1891	19	13.30	12	13.34	12	13.34	13.34	100	160	....
1893	31	33.56	12	32.70	12	36.07	32.70	103	144	....
1894	40	34.50	12	39.44	18	39.45	35.76	96	116	....
1895	22	35.98	18	35.64	20	35.94	32.30	111	113	....
1896	23	34.01	20	33.60	21	33.72	30.20	112	115	....
1897	23	37.60	21	37.87	5	38.54	33.91	114	129	....
1898	25	27.30	5	33.00	5	33.00	29.03	94	88	....
1899	5	32.18	5	32.18	5	32.18	28.31	114	120	....
1900	9	38.20	5	39.50	5	39.50	34.75	110	119	....
1902	12	26.00	5	28.14	8	28.95	24.75	105	120	....
1903	11	17.20	8	19.56	10	18.13	16.72	103	93	....
1904	10	25.88	10	25.88	10	25.88	23.87	108	85	....
1905	11	27.95	10	27.93	8	29.53	25.77	109	116	....
1906	11	25.30	8	25.96	6	26.33	22.62	112	112	....
1907	9	37.90	6	39.73	5	40.12	34.18	111	122	....
1908	78	29.01	5	32.03	5	32.03	27.28	106	113	116
1909	60	19.13	5	21.58	48	19.92	18.38	104	96	148
1910	56	28.09	48	28.98	40	29.03	26.74	105	111	105
1911	57	32.08	40	32.85	29	33.13	30.24	106	104	112
1912	53	21.56	29	35.00	35	23.38	21.16	102	82	140
1913	41	21.37	35	21.63	23	22.32	19.57	109	102	134
1914	42	33.56	23	34.27	21	34.70	30.04	112	101	122
1915	27	22.53	21	23.16	17	23.33	20.05	112	119	109
1916	23	24.95	17	25.41	16	25.84	21.83	114	115	113
1917	18	23.69	16	24.00	17	23.93	20.27	117	108	122

TABLE 2 — *Continued.*

1918	25	19.12	17	19.50	13	19.70	16.31	116	101	140
1919	25	19.28	13	19.92	13	20.06	16.69	116	94	151
1920	21	27.54	13	27.90	13	27.90	23.21	119	114	136
1921	13	16.60	13	16.61	......	....	13.81	120	77	162

The 12 varieties in column 6 in 1890 are the same as those in column 4 for 1891, and so on for all years.

Columns 10 and 11 are added to show the contrast in behavior. Note that in any year when Fultz made an index of less than 100, Mammoth Red scored 140 or more. 83

Average index of 1890	100
Average index of all varieties in 1890 that were retained for three or more years	114
Best five varieties that were on test in early years	126
Best five now on test	129
Best variety now on test	

Since the index removes from consideration any change that takes place within average varieties while they are on test, all advances and declines are merely relative. To get an actual measure of this, it is apparently necessary to take seed of two or more varieties, one with an ascending, another with a descending index. *A part of this seed should be planted in the regular variety test, the remainder should be saved through as many years as it will retain vitality. It should then be planted*, and the seed again divided into two parts — one part to be saved as before, while the other is planted beside seed of the same variety that has remained on test each year. This process ought to be continued until it is possible to determine from the ever-widening gap that may appear between the two indices for each variety, whether the advances and declines are actual or merely relative. For, if seed from deferred generations should have an index becoming gradually higher than the normal one, it is an indication that varieties have a tendency to slowly decline in yield, or to "run out." Such a tendency, if it applies to most varieties, can not be seen from the index and can be determined only by such a test.

Some of the many uses of an index such as the one here described may now be pointed out. By its use, the yielding power of standard varieties today may be compared with the power of the same varieties, and of others, years ago. The comparative responses of different varieties to soil and to season may be learned and analyzed, and the information so obtained may act as a valuable guide in selecting parents for crosses.

As an indication of the first use, the data presented in table 2, column 9, show that the average yielding ability of all varieties on test has advanced from 83 in 1890 to 120 in 1921. But many of the early varieties were dropped after one year's trial, or before they could demonstrate their true worth, so that 100 (the yield of all that were carried for three or more years) may be considered as the original base. The five best varieties that have been carried for ten or more years and are still on test have an average index of 126. Their seed has been widely distributed over the state, and the best figures obtainable indicate that about 70 percent of the wheat acreage in Maryland is now planted to these varieties.

Work by Metzger and Sando at this Station indicates that high rainfall in March and in May generally causes low wheat yields. A correlation of $+.839 \pm .053$ exists between the combined rainfall of March and May and the yearly indices of the Mammoth Red variety. This indicates that high rainfall in these months affects Mammoth Red much less than average varieties. A correlation of $-.632 \pm .108$ for Fultz shows that this variety is very seriously

affected. In Table 2, column 10, it will be observed that, as a whole, the indices for Fultz have remained fairly constant for the past twenty-nine years. Yet in some cases they have been markedly affected by such unfavorable years. During this period the actual yields have varied so much that a study of them can not bring out these facts as the indices can.

The third use for this index is strikingly illustrated in Table 3. The average yields of wheat in 1921, 1918, 1909, 1919, 1913, and 1912, were such that they may be considered as poor wheat years, while other years since 1907 may be considered as good. (1917 is omitted because some of the leading varieties were not on test in that year.)

TABLE 3.—*Comparison of indices for six varieties of wheat during poor years and good years.*

	Bearded purple straw.	Dietz long-berry.	Turkish amber.	Mammoth Red.	China.	Currell's prolific.
Average index for poor years......	136.3	124.5	132.5	145.9	126.9	114.3
For good years....	119.1	121.0	118.7	117.1	123.1	124.4

In the poor years, Mammoth Red yielded better than any other variety on test; while in good years Currell's prolific has done best. Unless factors that can not be combined in one individual, such as difference in time of ripening, are responsible for this condition, it is reasonable to expect that among the progeny of a cross between Mammoth Red and Currell's prolific a type may be selected that approaches 145.9 in poor years and 124.4 in good ones.

But an even more striking contrast is found among the pure-line selections from these varieties. For four years, 2,008–4–12, selected from Mammoth Red, has been planted beside its parent. In 1915 and 1916, when the parent showed an average index of 111, the selected strain showed an index of 115, an advance of 4 points. In 1920 and 1921, when the average index of the parent was 149, the index of this selection was 165.5, an advance of 16.5 points. Thus the apparent tendency of this selection is to exaggerate the peculiarity of its parent. Further, 89–16–14, from Currell's prolific has been planted for the past two years beside the variety from which it was selected. In 1921, when Currell's scored 90.8, the selected strain as an average of duplicate comparisons, scored 86.5, a loss of 3.5 points. In 1920, when the index of the parent was 127, this selection scored 131.7, or a gain of 4.7 points. Here again is a selection with a tendency to exaggerate the peculiarity of its parent. If these two continue to behave as they have done, may not a cross between them have even greater possibilities than a cross between unselected Mammoth Red and Currell's prolific?

BORDER EFFECT AND WAYS OF AVOIDING IT.[1]

In 1917 and 1918, when the extent of border effect for spring-sown oats, wheat and barley was determined (1, 2) it was noted that winter wheat, growing under similar conditions, appeared to have more marked border effect than the spring grains.

In 1921, the border effect in winter grains was as marked as usual and its extent was determined for a limited number of varieties. These data, considered in connection with that secured in previous years, extend the information over another year and to an additional crop.

Since border effect has been shown to be a factor in the reliability of plot tests, possible methods of preventing its occurrence and hence obviating the necessity and consequent expense of the removal of marginal areas have been of interest.

Growing varieties in contiguous plots without the intervention of alleys is open to several objections. Inability to distinguish exactly where one plot leaves off and the other begins when contiguous varieties are similar, and the practical impossibility of maintaining varieties pure, are mechanical difficulties. However, the more serious objection is the possible effect of one variety on another (3, 4, 5, 6)[3] when grown in this way, particularly since any one variety is flanked on either side by different varieties. Sowing the variety plots without the intervention of alleys, therefore, does not obviate the necessity of the removal of border rows.

The use of spring sown winter wheat on either side of each plot of spring-sown grain has been mentioned in this connection (7). Employing this method provides a uniform border which is in effect a cropped alley for all varieties in a test and in that respect is similar to the use of uncropped alleys. However, there is the possibility of the variety of winter wheat used in the cropped alleys reacting differently on the different varieties in a test. This effect might possibly be obviated to some extent by using seed of a number of winter wheat varieties composited instead of that of one variety only.

While the results of previous work appeared to make the efficiency

[1] Published with the approval of the Director, as Paper 316 of the Journal Series of the Minnesota Agricultural Experiment Station.

[2] Head of Section of Farm Crops, Division of Agronomy and Farm Management, Department of Agriculture, University of Minnesota.

[3] Reference by number is to "Literature Cited," p. 278.

of this method somewhat doubtful (6, 7). [illegible] it out carefully. This was done during [illegible] results form the main basis for this article.

TECHNIC OF THE EXPERIMENT.

All determinations of yields were made from plots located on University farm. The soil is a Hempstead silt loam not representative of any large section of the state. However, previous work (1, 2, 3) indicates that border effect on various types of soil approximating each other in productivity varies according to climatic conditions and effects of previous cropping.

The winter wheat varieties were sown September first, 1920, in plots made up of 16 six-inch drill rows each, a total width of eight feet. There were four plots of each variety. The length after the ends had been trimmed off square was 130 feet. Each two plots were separated by an uncropped space or alley 18 inches in width. There were four plots each of the spring wheat varieties and three each of the oat and barley varieties. Each plot of the spring grains was made up of 12 six-inch drill rows of oats, wheat or barley bordered on either side by 2 six-inch drill rows of winter wheat, and was 130 feet long. The winter wheat on either side of each plot was sown at the same time as the spring grains so that it would not be handicapped in its competition with them because of later seeding. For convenience in seeding, tight fitting removable partitions of tin were placed in the drill box to separate off the outer two drill cups on either end. The two outer compartments thus separated off were kept filled with Minturki winter wheat at all times when the spring grain varieties were being sown. This winter wheat at first made about the same progress as the spring grains but the plants were more procumbent and did not joint. The winter wheat in the cropped alleys consequently was not in the way at harvest time.

There was approximately an 18-inch space between the outside drill rows of adjacent plots of winter wheat. Three inches of this space on either side belonged to the plot adjacent to it. This left a 12-inch uncropped space between adjacent plots.

In the spring grains, there was a space approximately twenty-four inches wide between the outer drill rows of adjacent plots occupied by four 6-inch rows of winter wheat.

Weeds grew both in the unoccupied alleys between each two plots of winter wheat and in the areas between each two plots of spring grain occupied by the four drill rows of winter wheat. The largest of these were removed by hand.

From the plots of the winter wheat varieties, three drill rows on either side were separately removed by hand at harvest, bound and tagged. In the [illegible] ows between plots were disregarded an[illegible] ain removed from either side of each plot in the same manner as from the winter wheat. These rows are referred to as outside, middle and inside border rows respectively.

The remaining ten drill rows in the winter wheat varieties and the six rows in the spring grain varieties were harvested with the binder. The oat and barley varieties were lodged and hence there was more or less loss in harvesting the central rows with the binder. Since the border rows were cut by hand, practically no loss occurred in the harvesting operation. This difference in method of harvesting the portions of the plots accounts to some extent for the difference in yields between the inside border rows and the average for the central rows for the oats and barley crops. In the wheat variety plots both winter and spring there was practically no loss in harvesting the central rows with the binder.

The entire product from each portion of each plot harvested separately was weighed and threshed with a small machine.

The straw weights for the most part paralleled the grain weights and therefore are not given in the tables which are presented in this paper.

The grain yields were computed for each area harvested separately. Each border row occupied an area 6 inches by 130 feet or 1/670.15 acre. The central areas in the winter wheat varieties were 10 drill rows or 5 feet wide and 130 feet in length of 1/67.015 of an acre in size. In the spring grain varieties, the central areas were 6 drill rows wide or 3 feet by 130 feet long or 1/101.68 of an acre in size.

After the yields for each portion of each plot had been computed separately, the necessary computations were made to secure the yields with none, one, two and three border rows removed, respectively. This was done by adding together the weights in pounds from all portions of each individual plot to show the weight with no border rows removed. The weight in pounds of the two middle and the two inside border rows added to that from the central rows gave the product with one border row removed from either side. The yields with two border rows removed were secured in a similar manner.

The standard deviations and probable errors were computed in the usual manner. All computations have been checked.

THE EFFECT OF UNCROPPED AND CROPPED ALLEYS ON THE YIELDS OF DIFFERENT PORTIONS OF PLOT

The plants in the border rows of the winter wheat varieties separated by uncropped alleys appeared darker green and slightly taller than those within the plots during late October of 1920; and in the spring when growth had well started, the same effect was noticeable, becoming more marked at jointing and heading time. At no time during the growing period was border effect plainly visible on the plots of spring grains flanked by alleys cropped to winter wheat. The border rows were not appreciably taller than the others and appeared to be no later in maturity. Counts of the numbers of culms per unit of row for the various portions of the same plots would probably have given an indication of what might be expected; but these were not made. Observations were made on nearby spring-sown plots of oats, wheat and barley separated by uncropped alleys and from jointing time on these were found to have the border effect more or less plainly visible. Much the same effect was noted on plots at the various substations and various outlying experimental fields in the state.

The yields for the different portions of both the winter wheat varieties separated by uncropped alleys and the spring grain varieties separated by alleys cropped to winter wheat together with percentage increases based on the yields of the central rows are given in Table 1.

The data for 1918 and 1917 are included in the table to facilitate comparison of results for the three seasons.

An examination of the yields of the various portions of the winter wheat plots shows that the outside border rows yielded at the rate of 33.67 bushels, the central rows at the rate of 18.86 bushels and the inside rows at the rate of 14.92 bushels, as compared with the yield of 15.95 bushels for the central rows.

In percent, the outside border rows yielded 211.1, the middle border rows 118.2, and the inside border rows 93.5 of the yield of the central rows. Comparison of these percentages with those for the same portions of the spring wheat plots in 1918 and 1917 shows a striking similarity, when the fact is taken into consideration that the determinations were made in different seasons and that one is a winter grain and the other a spring grain.

Bearing in mind the fact that the alleys between plots in the spring-sown oats, wheat and barley were occupied by spring-sown winter wheat, it is of considerable interest to note that for each of the three crops the outside and middle border rows show considerably higher yields than the inside border rows or the central

TABLE 1.—*Average yields in bushels per acre of varieties of oats, spring wheat, barley, and winter wheat harvested from border drill rows, spaced 6 inches apart, removed from either side of each plot, bordered by spring-sown winter wheat in 1920 and flanked by alleys only in 1918 and 1917. Also the yields from the central rows remaining after the removal of the border rows, and the yields of the border rows in percentages based on the yields of the central rows.*

Year and source.	Oats. Number of rows or plots.	Oats. Average yield per acre. Bushels.	Oats. Average yield per acre. Percent.	Spring wheat. Number of rows or plots.	Spring wheat. Average yield per acre. Bushels.	Spring wheat. Average yield per acre. Percent.	Barley. Number of rows or plots.	Barley. Average yield per acre. Bushels.	Barley. Average yield per acre. Percent.	Winter wheat. Number of rows or plots.	Winter wheat. Average yield per acre. Bushels.	Winter wheat. Average yield per acre. Percent.
1921:												
Outside border rows.....	24	65.58	199.9	32	30.56	153.6	24	48.93	213.5	26	33.67	211.1
Middle border rows......	24	58.53	170.4	32	25.75	127.4	24	42.74	186.5	26	18.86	118.2
Inside border rows.......	24	49.95	152.3	32	22.23	111.7	24	33.56	146.4	26	14.92	92.5
Central rows...........	12	32.80	100.0	16	19.90	100.0	12	22.92	100.0	13	15.95	100.0
1918:												
Outside border rows.....	112	142.80	189.4	56	73.10	208.9	72	99.90	194.4	......	......	......
Middle border rows......	112	82.80	109.8	56	40.80	116.6	72	60.90	118.5	......	......	......
Inside border rows.......	112	80.00	106.1	56	39.80	113.7	72	55.80	108.6	......	......	......
Central rows...........	56	75.40	100.0	28	35.00	100.0	36	51.40	100.0	......	......	......
1917:												
Outside border rows.....	88	131.97	184.9	40	55.00	204.4	32	97.73	238.0	......	......	......
Inside border rows.......	88	87.95	123.2	40	40.98	149.3	32	64.56	150.3	......	......	......
Central rows...........	44	71.37	100.0	20	27.25	100.0	16	42.87	100.0	......	......	......

rows. The data for the yields from the outside border rows of the plots, expressed in percent based on the yields of the central rows, are 199.9 for the oats, 153.6 for the wheat and 213.5 for the barley as compared with 100 for the inside rows. These comparative yields indicate that the rows of winter wheat in the alleys *did* not prevent border effect.

The increases in yields due to border effect, expressed in percent based on the yields of the central rows, are for the outside rows 199.9 for the oats, 153.6 for the wheat and 213.5 for the barley and the middle rows in same same order 170.4, 127.4 and 186.5 respectively. The border effect on the wheat appears to be relatively lower than for the other crops; but this difference is not a real one. The border effect on the oats and barley as indicated by the yields is somewhat higher than it should be due to the unavoidable loss of grain in harvesting the lodged central rows of these crops with the binder. The results, although somewhat lower for wheat, are similar to the results for the same crops in 1918 and 1917.

Based on yields of the central rows, the three-year average of the outside border rows, expressed in percent, for all crops is 199.8 and for the middle border rows (inside rows of 1917) it is 138.02. The outside border rows, therefore, averaged for the three-year period double the yield of the central rows and the middle border rows averaged for the same period over one-third more than the central rows.

BORDER EFFECT AND THE INTERPRETATION OF YIELDS.

In the former articles (1,2) attention was called to the fact that border effect due to alleys not only increases the yields of plots, the amount of increase depending on the size and shape of the areas used, but also may change the rank of varieties or rates of seeding in tests of that nature.

From the data given in Table 1 it is evident that spring-sown winter wheat growing in the alleys between each two plots of spring grains did not obviate border effect. Therefore, it appears desirable to use the 1921 data in determining the increases in yields from plots due to border effect on (a) each of the three border rows on either side of each plot separately, (b) on the outside and middle border rows combined, and (c) on the outside, middle and inside rows combined for spring and winter wheat. The data for the 1921 crop together with the data for 1918 and 1917 crops make possible the comparison of results for a three-year period. The increases in yields for the three-year period expressed in bushels and in percent are given in Table 2.

TABLE 2.— *Comparison of the increases in yields expressed in bushels per acre and in percents from plots of oats, wheat, and barley due to marginal effect on the outside, middle, and inside border rows on either side of each plot, the increases on the outside and middle rows combined, and the increases on the outside rows.*

		1921.				1918.				1917.		
			Increase in yields from plots due to border effect on the rows as follows:				Increase in yields from plots due to border effect on the rows as follows:				Increase in yields from plots due to border effect on rows as follows:	
Crop	Number of border rows removed from either side of each plot.	Yield per acre.	Outside rows.	a. Outside and middle. b. Middle rows.	a. Three rows. b. Middle and inside rows. c. Inside rows.	Yield per acre	Outside rows.	a. Outside and middle. b. Middle rows.	a. Three rows. b. Middle and inside rows. c. Inside rows.	Yield per acre.	Outside rows.	a. Outside and middle rows. b. Middle rows.
		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Oats	None	46.31	......	....	....	83.4	......	....	....	80.5	......	....
	One	42.05	4.26	a8.84	....	75.9	7.5	a8.2	a9.1	73.6	6.9	a9.1
	Two	37.47	......	b4.58	....	75.2	......	b0.7	b1.6	71.4	......	b2.2
	Three	32.80	......	....	....	74.3	......	....	c0.9	....	......	....
			Percent.	*Percent.*	*Percent.*		*Percent.*	*Percent.*	*Percent.*		*Percent.*	*Percent.*
	One	......	10.13	a23.59	....	....	9.87	a10.90	a12.25	....	9.38	a12.74
	Two	......	......	b12.22	....	....	......	b 0.93	b 2.15	....	......	b 3.08
	Three	......	......	....	....	....	......	....	c 1.20	....	......	....
		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Spring wheat	None	23.46	......	....	....	40.8	......	....	....	32.5	......	....
	One	21.86	1.60	a2.81	a3.56	36.4	4.4	a5.0	a5.7	29.2	3.3	a5.21
	Two	20.65	......	b1.21	b1.96	35.8	......	b0.6	b1.3	27.3	......	b1.90
	Three	19.90	......	....	c0.75	35.1	......	....	c0.7	....	......	....
			Percent.	*Percent.*	*Percent.*		*Percent.*	*Percent.*	*Percent.*		*Percent.*	*Percent.*
	One	......	7.32	a13.61	a17.89	....	12.09	a13.97	a16.24	....	11.30	a19.05
	Two	......	......	b 5.86	b 9.85	....	......	b 1.68	b 3.70	....	......	b 6.96
	Three	......	......	....	c 3.77	....	......	....	c 1.99	....	......	....

TABLE 2 — *continued.*

		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Barley.........	None	33.04	......	....	....	58.3	......	....	....	51.4	......	....
	One	29.28	3.76	a7.24	....	53.2	5.1	a6.3	a6.9	45.8	5.6	a8.5
	Two	25.80	......	b3.48	....	52.0	......	b1.2	b1.8	42.9	......	b2.9
	Three	22.92	......	....	....	51.4	......	....	c0.6	....	......	....
			Percent.	*Percent.*	*Percent.*		*Percent.*	*Percent.*	*Percent.*		*Percent.*	*Percent.*
	One	......	12.84	a28.06	....	....	9.59	a12.12	a13.42	....	12.23	a19.81
	Two	......	......	b13.49	....	....	......	b 2.31	b 3.50	....	......	b 6.76
	Three	......	......	....	....	....	......	....	c 1.17	....	......	....
		Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
Winter wheat...	None	18.84	......	....	....	....	......	....	....	....	......	....
	One	16.45	2.39	a2.95	a2.89	....	......	....	....	....	......	....
	Two	15.89	......	b0.56	b0.50	....	......	....	....	....	......	....
	Three	15.95	......	....	....	....	......	....	....	....	......	....
			Percent.	*Percent.*	*Percent.*		*Percent.*	*Percent.*	*Percent.*		*Percent.*	*Percent.*
	One	......	14.53	a18.56	a11.85	....	......	....	....	....	......	....
	Two	......	......	b 3.52	b 3.13	....	......	....	....	....	......	....
	Three	......	......	....	....	....	......	....	....	....	......	....

TABLE 3.— *Summary of the increases in yields from plots due to border effect.*

Crop.	Increases in yields expressed in percent due to border effect on outside rows only.				Increases in yields expressed in percent due to border effect on outside and middle rows combined.				Increases in yields expressed in percent due to border effect on three border rows on either side of each plot.	
	1921.	1918.	1917.	3-year average.	1921.	1918.	1917.	3-year average.	1921.	1918.
Oats..........................	10.13	9.90	9.40	9.81	23.60	10.90	12.70	15.73	....	12.30
Spring wheat..................	7.32	12.09	11.30	10.24	13.61	13.97	19.05	15.54	17.89	16.24
Barley.........................	12.84	9.59	12.23	11.55	28.02	12.12	19.81	19.98	....	13.42
Winter wheat...................	14.53	......	......	......	18.56	......	......	......	....	....
Average for all crops.........				10.93				17.23		

A summary of the increases in yields of the plots due to border effect on the marg[illegible], is presented in Table 3.

The percentages of increase for the plots due to border effect on the outside rows, with the exception of that for spring wheat in 1921, are rather uniform for the three-year period, the mean being 10.96 per cent.

For the outside and the middle rows combined, the percentages of increases for the oats and barley in 1921 is rather high in comparison with the same results for the other two years. The mean for all of the determinations for the three-year period is 17.23 per-cent.

Data regarding border effect on three border rows on either side of each plot is available for only two years. The results for oats and barley in 1921 are not comparable with the others and therefore no average is taken. Under ordinary conditions it appears that the amount of border effect on the third row on either side of each plot is not a serious consideration. The yield of each variety, as determined from yields from plots of full size and with one, two, and three border rows removed from either side of each plot is given in Table 4. The varieties of each crop are first listed in order of yield as determined from plots from which no border rows were removed. The yield for each variety is then given with one, two, and three border rows removed.

In order to make comparisons of the value of the several varieties of each crop by each of the four methods of test, i. e., with none, one, two, and three border rows removed from either side of each plot, it is convenient to establish a discard point for the season. This has been accomplished by employing the formula

$$\frac{\text{Standard deviation x .6745}}{\sqrt{n}}$$

to derive the probable error for each test. In the formula, n represents the number of replicates of each variety. After the probable error for the four methods of test had been derived for the different crops, each was multiplied by the factor 3.8 which gives odds of 30 to 1 (8) against a difference between any two varieties being due to normal variation. This gives differences in bushels for none, one, two, and three border rows for each crop as follows: Oats, 4.98, 4.51, 4.90, and 5.89; spring wheat, 1.71, 2.05, 2.58, and 3.00; barley, 3.42, 2.81, 2.39, and 3.12; winter wheat, 1.21, 1.75, 1.63, 1.37, respectively. The figure obtained for each crop and method of test has been subtracted from the highest yielder and a line drawn indicating the discard point for the season under each method of test.

TABLE 4.—*Comparison of average yields per acre, in 1921, for three 1/55-acre plots (approximate size) of four varieties of oats and barley, and four plots of the same size of four varieties of spring and winter wheat with no border rows removed, and with one, two, and three border rows removed from either side of each plot.*

Crop and variety.	Number.	Descriptive note.	No border rows removed.			One border row removed.			Two border rows removed			Three border rows removed.		
			Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.	Yield per acre.	Standard deviation.	Rank.
OATS		Time of maturity:	*Bu.*			*Bu.*			*Bu.*			*Bu.*		
Sixty Day [1]	674	Early	50.67	2.26 ± 0.62	1	46.00	1.48 ± 0.41	1	41.36	1.39 ± 0.38	1	36.10	1.71 ± 0.47	2
Minota [1]	512	Medium early	[2] *47.30*	7.66 ± 2.11	2	[2] *44.03*	6.10 ± 1.68	2	[2] *40.14*	6.10 ± 1.68	2	[2] *37.54*	5.62 ± 1.55	1
Victory	514	Medium	44.12	4.31 ± 1.19	3	38.71	3.91 ± 1.08	4	33.51	4.00 ± 1.10	4	28.00	4.15 ± 1.14	4
Iowa 103	531	Early	43.14	1.30 ± 0.36	4	39.46	2.31 ± 0.64	3	34.88	3.75 ± 1.03	3	29.56	6.87 ± 1.80	[illegible]
Average			46.31	3.88 ±		42.05	3.45 ±		37.47	3.81 ±		32.80	4.59 ±	
SPRING WHEAT		Type:												
Marquis	1239	*vulgare*	24.83	1.07 ± 0.25	1	23.10	1.48 ± 0.35	2	21.91	1.68 ± 0.40	2	21.46	1.88 ± 0.45	
Arnautka	2103	Durum	[2] *24.60*	.81 ± 0.19	2	[2] *23.21*	.69 ± 0.17	1	[2] *21.98*	1.07 ± 0.25	1	[2] *21.12*	1.27 ± 0.30	
Preston	924	*vulgare*	22.95	2.73 ± 0.65	3	20.53	3.26 ± 0.78	4	18.98	4.10 ± 0.98	4	17.29	4.87 ± 1.16	
Spring Emmer	1165	*dicoccum*	21.35	.71 ± 0.17	4	20.59	.94 ± 0.22	3	19.72	1.28 ± 0.30	3	19.71	1.36 ± 0.33	
Average			23.46	1.33 ±		21.86	1.59 ±		20.65	2.03 ±		19.90	2.35 ±	
BARLEY		Type:												
Minsturdi [1]	439	True 6-row	[2] *43.32*	3.15 ± 0.87	1	[2] *40.54*	2.48 ± 0.68	1	[2] *36.05*	2.83 ± 0.78	1	[2] *32.78*	3.04 ± 0.84	
Svansota [1]	440	2-row *erectum*	32.49	2.54 ± 0.70	2	28.70	1.96 ± 0.54	2	25.14	.02 ± 0.01	2	22.70	.98 ± 0.27	
Chevalier [1]	230	2-row *nutans*	29.51	.03 ± 0.01	3	26.32	.05 ± 0.01	3	23.97	.84 ± 0.23	3	21.95	2.16 ± 0.60	
Improved Manchuria [1]	184	6-row common	26.85	4.91 ± 1.35	4	22.27	4.22 ± 1.16	4	18.05	3.77 ± 1.04	4	14.25	3.56 ± 0.98	
Average			33.04	2.66 ±		29.28	2.18 ±		25.80	1.87 ±		22.92	2.44 ±	
WINTER WHEAT		Type and time of maturity												
Minturki [1]	1507	*vulgare*, med	[2] *22.31*	1.57 ± 0.43	1	[2] *19.30*	1.43 ± 0.39	1	[2] *18.68*	1.58 ± 0.44	1	[2] *18.83*	1.71 ± 0.47	
Minhardi [1]	1505	*vulgare*, med	18.74	.52 ± 0.14	2	16.61	.38 ± 0.11	2	16.10	.25 ± 0.69	2	16.28	.15 ± 0.04	
Odessa	943	*vulgare*, late	18.51	.81 ± 0.22	3	15.84	1.09 ± 0.30	3	15.67	.87 ± 0.24	3	15.74	.82 ± 0.22	
Buffums 17	1651	*vulgare*, med	15.82	.95 ± 0.23	4	14.04	1.52 ± 0.36	4	13.11	1.43 ± 0.34	4	12.97	1.56 ± 0.37	
Average			18.84	.96 ±		16.45	1.36 ±		15.89	1.28 ±		15.55	1.06 ±	

[1] From Plant Breeding Section, University Farm. [2] Discard point for crop season.

In the oat varieties, the removal of two and three border rows from either side of each plot involves two changes in rank, but in neither instance does the change involve a change of the variety from one side of the discard point to the other.

In the spring wheat tests, the removal of two border rows from either side of each plot, changes the rank of the spring emmer and moves it above the discard point for that method of test. This position is maintained where three rows are removed from either side of each plot.

In the barley and winter wheat tests, the removal of border rows brought about no changes of rank.

SUMMARY AND DISCUSSION OF RESULTS.

The results show that, in 1921, there was increased yield in the outside and middle border rows for the winter wheat varieties where the alleys were not cropped and for the spring grains separated by alleys cropped to winter wheat. The effect on the inside border rows (the third from the outside of the plots) was nil for the winter wheat and slight for the spring wheat.

Cropping the alleys between the plots of spring grains to winter wheat reduced border effect so that it was not plainly evident at any time before the grain was harvested. This reduction is reflected in the relatively lower yields of the outside border rows of spring wheat, expressed in percent based on the yields from the central rows, as compared with the results secured in 1918 and 1917. For the oat and barley varieties, this reduction in border effect is not apparent from the yields of the outside rows expressed in percentages of the central rows because the fact that there was unavoidable loss of grain in harvesting the lodged central rows with the binder. This resulted in yields lower than they should be from the central rows and consequently higher percentages for the outside rows based on the yields from the central rows.

The three-year average yields of the outside rows of oats, spring wheat and barley expressed in percent based on the yields of the central rows is 199.8 and that of the middle border rows (inside rows in 1917) is 138.0.

Results secured in 1917 with Kubanka wheat (9), under dryer conditions, were 182.4 per cent for the outside and 127.7 percent for the second rows based on the yields of the six central rows. All portions of the plots were harvested by hand. The effect did not extend to the third rows in the plots. The uncropped alleys varied from 16 inches to 38 inches and one was a cultivated roadway several feet in width. There appears to be some correlation between width of alley and amount of border effect but the number of determinations

was too small to give conclusive results. The amount of increase in yield in the border rows in this trial is very similar to the three-year average under Minnesota conditions.

The yields of the outside and inside border rows in the variety plots separated by alleys were in almost every instance considerably higher than the yields from the central rows. Where variety or rate of seeding plots have been planted without the intervention of alleys, border rows have given yields both considerably above and below the yields for the central rows. This point is brought out in work reported from Nebraska (5). Although no statement is made regarding the plan of the plots in the variety and rate of seeding trials, it is assumed that there were no alleys between these plots. Therefore, the plants in contiguous plots came into direct competition and both higher and lower yields resulted in the border rows as compared with the yields from the central rows.

Available data emphasize the necessity of considering border effect seriously in variety and rate of seeding trials, both when no alleys intervene and when the plots are separated by cropped or uncropped alleys.

The results for the varieties separated by alleys in plots without and with border rows removed for a three-year period, show that the removal of the outside border row from either side of each plot reduced yields approximately 10 percent and when two border rows were removed from either side of each plot the yields were reduced approximately 17 percent. When the border effect extended to the third row (inside border row) it was relatively unimportant.

That border effect in plots separated by uncropped alleys does make a different interpretation of results necessary in some instances has been shown (1). In 1921, the third year that work of this kind was carried on, one variety was moved from below to above the discard point for the year by the removal of border rows.

The fact that on each of the three years, one or more varieties or rates of seeding was moved from one side to the other of the discard point for the year by the removal of border rows compels the conclusion that this operation was necessary in order to secure reliable results.

It is possible that under other conditions this operation may not be necessary. Careful experimentation covering a period of years is the only way in which this point can be settled.

The knowledge that border effect is not uniform for all varieties precludes the use of any percentage figures derived in one place to reduce yields secured in another location to a border-effect-free basis.

LITERATURE CITED.

1. ARNY, A. C. and H... ...hnic in plot tests. *In* Jour. Agric. Re...

2. ARNY, A. C. Further experiments in field plot technic. *In* Jour. Agric. Res., v. 21:483-499. 1921.

3. FLETCHER, F. Note on a toxic substance excreted by the roots of plants. *In* Mem. Dept. Agric. India, Bot. Ser., v. 2:1-16. 1908.

4. HAYES, H. K. and ARNY, A. C. Experiments in field technic in rod-row tests. *In* Jour. Agric. Res., v. 11:399-419. 1917.

5. KIESSELBACH, T. A. Studies concerning the elimination of experimental error in comparative crop tests. Nebr. Agr. Exp. Sta. Research Bul. 13. 1918.

6. MONTGOMERY, E. G. Competition in cereals. Nebr. Agr. Exp. Sta. Bul. 127. 1912.

7. WIANCKO, A. T., ET AL. Report of Committee on Standardization of Field Experiments. *In* Jour. Amer. Soc. Agron., 10:345-354. 1918.

8. WOOD, T. B. and STRATTON, F. J. M. The interpretation of experimental results. *In* Jour. Agric. Sci., v. 3:417-440. 1910.

9. MARTIN, J. H. Unpublished data secured at Newell, South Dakota, in 1917.

THE EXTENT OF NATURAL CROSS-POLLINATION IN SOYBEANS.[1]

C. M. WOODWORTH.[2]

INTRODUCTION.

The soybean is normally a self-fertilized plant. The flowers are extremely small, so small, in fact, that manipulation during artificial crossing is almost impossible without the aid of a binocular or a hand lens. There are ten stamens closely surrounding the pistil, and at the time when the stigma is receptive, the anthers burst open, covering the stigma with an abundence of pollen grains. As pollination occurs just before the flower opens, the chances of foreign pollen gaining entrance and effecting fertilization are very small.

NATURAL HYBRIDS.

Nevertheless, some natural crossing does occur. Piper and Morse (1)[3] found in bulk seed produced in 1907 certain oddly colored seeds, some of which produced plants whose progeny showed segregation in seed color, pubescence color, and flower color, thus proving the original seeds to be hybrids. They believe, however, that cross-

[1] Papers from the Department of Genetics, Agricultural Experiment Station, Madison, Wisconsin, No. 31. Published with the approval of the Director of the Station. Received for publication, March 15, 1922.

[2] Formerly Assistant in Genetics; now Assistant Chief in Plant Breeding, at Illinois Agricultural Experiment Station.

[3] Reference by number is to "Literature cited," p. 283.

ing in soybeans is far from common, and ... hybrids that occur is very small, per[illegible] hundred."

Woodhouse and Taylor (2) conclude from their observations at Sabour, India, that "natural crosses do not occur on the plains of India to such an extent" as that noted by Piper and Morse in America. They grew seventy-five or more plots, each derived from a single plant selection, and found only one of these to be a hybrid (presumably so-called because it showed segregation in one or more characters, while the other plots did not). In a few other plots rogues were found which may have been the result either of crossing or of chance admixture. These had not yet been tested when the above work was published.

In the work of the Department of Genetics of the Wisconsin Agricultural Experiment Station with soybeans, in 1914, it was observed that the progeny of a single plant was of two types with respect to growth habit. One type was stocky, compact, low and early maturing; the other was stout, more luxuriant in growth, higher yielding and later maturing. These two types occurred in the ratio of three of the late maturing to one of the early maturing type. Also, in the same year, progeny of another single plant showed two different and distinct pod colors, one a very dark brown, the other a light brown. The ratio of plants bearing dark brown pods to those bearing light brown pods was, again, as three to one.[1] Progenies of other single plants have been noted which showed evidence of segregation in flower color, seed color, cotyledon color, etc., and which were proof, therefore, of the hybrid nature of the parent Woodworth, 3).

The foregoing instances of segregation clearly show that natural crossing does occur in the soybean. In view of that fact, it was important in our experimental work to know how often we might reasonably expect natural hybrids to be produced among unbagged plants. An experiment was accordingly planned in 1916 to determine this point in a definite manner.

The writer is indebted to Professor L. J. Cole for helpful suggestions and advice in the conduct of these experiments.

EXPERIMENTAL.

Soybean flowers are either purple or white. Purple is dominant to white, and the two colors form an allelomorphic pair. Plants

[1] Detailed data on the inheritance of these characters will be presented at another time.

known to be homozygous for purple flowers were grown two feet apart in the row, and between every two of these, so that they alternated with them, white flowered plants were interpolated. As the branches of the two types intermingled, abundant opportunity was afforded for crossing between them.

Crossing might occur in any one of four different ways: (1) white flowers might cross with white, or (2) purple with purple on the same or on different plants; or (3) pollen from white flowers might fertilize purple; and lastly, (4) pollen from purple might fertilize white. Only the last named type of cross was made use of in this experiment since it is the only one in which the crossing can be readily determined in the plants of the succeeding generation. Seed from the purple-flowered plants will of course produce plants with purple flowers whether crossing has occurred or not, and hence these have no value as a test. Seed from the white-flowered plants will, if the flowers were self-pollinated, or fertilized by pollen from other white flowers, produce only plants bearing white flowers; but if crossing has occurred with the dominant variety, then such seed should produce some plants bearing purple flowers. The percentage of such hybrid seed, then, may be taken to represent about one-fourth of the total amount of crossing, since this is only one of four ways in which crossing may occur.

In the fall of 1916 many pods were saved from each of seven white-flowered plants from the rows previously mentioned, and these seeds were planted in the spring of 1917. Fifty-three pods from 3 of these plants were kept separate, and the seeds from each pod were planted together so that it could be determined whether, if one seed from a particular pod proved to be a hybrid, the other seeds from that same pod were hybrid also. A total of 91 plants was produced from these 53 pods, and all bore white flowers, thus showing no evidence of crossing. The remaining pods saved from the 3 plants above-mentioned, and all the pods saved from the other 4 plants, were shelled, so that the relationship of the beans to the pods was lost. These seeds produced 114 plants, all white-flowered. Altogether, therefore, 205 plants were grown and not one showed evidence of hybridity.

On the average, soybean pods of the white-flowered variety (S. P. I. 20405) used in this experiment contain 2 seeds. The 205 plants tested, represent, therefore, about 100 pods. If one pod were crossed the percentage of crossing would be 1 percent, if there were only this one way in which crossing could take place; but

since there are four different ways, and one is as likely to occur as any other, the true percentage of crossing would be 4 percent. However, not one pod out of the estimated 100 tested proved to be the result of a cross; hence we may conclude that for the varieties tested in this experiment and for this season the natural crossing was probably less, but at any rate, not greater than 4 percent.

In the second experiment, cotyledon color was substituted for flower color. As shown in another paper (Woodworth, 3) green cotyledon is recessive to yellow. While two factors for yellow (duplicates) were involved in the cross under consideration, the result, for our purpose, was the same as if only one factor were involved. The advantage in using cotyledon color instead of flower color in this experiment is evident in the fact that, like endosperm color in corn, it appears one generation ahead of a mature plant character, and the number of hybrid seeds can be obtained directly without having to test them. In this instance one could be reasonably sure that any yellow-cotyledoned seeds found among the greens borne by plants of the green-cotyledon type were hybrids.

In 1918, two plans of planting were followed. In the first plan (A), the first (outside) row was planted to Variety 8, a yellow-cotyledoned variety (S. P. I. 20406), the second row was planted to both Variety 8 and also Variety 9, a green-cotyledoned variety (S. P. I. 20854), the plants of the two varieties being alternated in the row. (These varieties flower at about the same time, though Variety 8 is a trifle earlier.) The third row was planted to Variety 8 alone, the fourth to the two varieties alternating, and so on. Thus the odd-numbered rows were planted to the yellow-cotyledon variety, while the even numbered rows were planted to both varieties. In the second plan (B), the two varieties alternated in every row. The plants in both plans stood one foot apart in the row, and the rows were one foot apart. Thus, as in the first experiment, abundant opportunity was afforded for natural crossing to occur. Only the green-cotyledoned plants were harvested, and besides the individual plant number they were designated A or B, according as they belonged to the A or the B plan of planting. In harvesting, the pods were picked from each plant, and each pod examined for hybrid seed.

Plants in plan A (43 in number) produced a total of 1,464 pods, of which only one was a hybrid. This pod bore two seeds, one of which had green, and the other yellow cotyledons. Plants in plan B (112 in number) bore a total of 6,016 pods, of which two contained hybrid seed. Both pods were three-seeded, and in one all the seeds

were hybrid, while in the other only one seed was a hybrid. Altogether, 7,480 pods were produced by the 155 plants harvested. Three of these pods contained hybrid seeds, or .04 of 1 percent. This number would be approximately equivalent to one hybrid pod in 2,500. Since this, however, is only one out of four ways in which crossing may occur, the actual proportion would be approximately one hybrid in 625 pods produced, or .16 of 1 percent. This figure is considerably lower than the estimate given by Piper and Morse (*loc. cit.*).

Direct proof of the hybrid nature of these yellow-cotyledon seeds has been presented in another paper (Woodworth, 3).

The percentage of natural hybrids above given is not thought to hold for all varieties, or for all localities, or for all seasons. Much depends on the time of flowering of the contiguously planted varieties, the intervening distance, and the presence or absence of minute insects, such as thrips, which are believed to play a large part in the occurrence of natural cross pollination of soybeans. It is necessary to secure more data on different varieties and in widely separated localities before one can arrive at a proportion which will be generally applicable.

As was indicated by the above data, a flower may be partly cross-pollinated and partly selfed. Indeed, this would appear to be the more general result as only one of the three hybrid pods contained seeds all of which were hybrid. This fact emphasizes the necessity of examining each pod separately.

HYBRIDS BY MUTATION.

Heterozygous plants may also arise as a result of mutation. Take the character flower color for illustration. If in a homozygous purple strain, the factor for purple should be lost or otherwise made ineffective by a mutative change in one gamete and no such change should occur in the other gamete, then the seed resulting from the union of these two germ-cells would produce a plant heterozygous for purple flowers. The progeny of such a plant would show segregation just as if the parent plant were the result of a natural cross. Of course, the number of mutations in soybeans is probably small, but it is reasonable to believe they do occur. It may even be probable that the progenies which segregated in growth habit in one case and pod color in the other (as noted above in our work) came from plants which were the result of mutation, tho the evidence appears to favor natural crossing as the cause. This emphasizes the fact, however, that little dependence can be

placed in the amount of crossing determined by the frequency of occurrence of heterozygous plants in the field.

PRACTICAL SIGNIFICANCE.

The experimental plant breeder must know at all times the source and parentage of the strains with which he works. Few, probably no, crop plants are exclusively self-fertilized, but there is great diversity among them with respect to the frequency with which natural crossing may occur. This relative frequency will determine what care should be taken in making sure of the purity of the breeding material. If, for example, natural crossing occurs so seldom that bagging all plants is rendered unnecessary, then that fact is worth knowing.

It is important that strains made pure by years of selection be kept pure. As soon as crossing occurs, deterioration in yield is a common result. Uniformity of product is also sacrificed, and market standards cannot be met, and the result is discrimination and reduced prices. If the producer knows the chances of crossing between his varieties and those of his neighbor, he can more intelligently determine the distances that should intervene between them to prevent such crossing.

SUMMARY.

1. Natural hybrids are shown to occur in the soybean.

2. In a total of 205 seeds from recessive white-flowered plants, none proved to be hybrid. When cotyledon color was used as an index of hybridity, only three pods in a total of 7480 contained hybrid seed. If all ways in which crossing may occur are taken into account the proportion would be one hybrid pod in 625, or .16 of 1 percent.

3. The percentage of cross-pollination may presumably differ according to the variety, the locality, and the season.

4. Hybrids may also arise by mutation.

5. It is important to the experimental plant breeder and to the farmer to know how much natural crossing may be expected under given conditions.

LITERATURE CITED.

1. Piper, C. V. and Morse, W. J. The soybean; history, varieties, and field studies. U. S. Dept. Agr. Bur. Plant Indus. Bul. 197. 1910.

2. Woodhouse, E. J. and Taylor, C. S. The varieties of soybeans found in Bengal, Bihar, and Orissa and their commercial possibilities. Mem. Dept. Agr. India, v. 5:103–175. 1913.

3. Woodworth, C. M. Inheritance of cotyledon, seed-coat, hilum, and pubescence colors. Genetics, 6:481–553. 1921.

THE EFFECT OF FERTILIZERS ON THE GERMINATION AND BACTERIAL DEVELOPMENT OF INOCULATED SOYBEAN SEED.[1]

T. B. HUTCHESON AND T. K. WOLFE.[2]

It is a common practice in Virginia for farmers to mix together seed and fertilizer and to sow the mixture from the same compartment of the drill. In this procedure, the seed and fertilizer come in intimate contact. The effects of the fertilizer material on the germination and the bacterial development of inoculated seed are of great importance. Questions in regard to these effects have often been asked by many of the people who have used this method of planting seeds.

The investigations reported in the paper were begun for the purpose of studying possible effects of certain fertilizer materials on the germination of inoculated soybean seed and the nodule development on the roots of the plants.

MATERIALS AND METHODS USED.

A sandy loam soil, on which soybeans had never been grown, was selected for this experiment. The soil was placed in flats one foot square and three inches deep. The experiments were conducted in the greenhouse. Soybean seed were inoculated with a pure culture of the soybean organism before planting and they were planted in direct contact with the different fertilizer materials. The rate of planting was two bushels per acre, which allowed fourteen seed to each flat. In addition to those fertilized, two flats were left unfertilized to serve as checks on the fertilizer materials. The fertilizers used and the rates of application are shown in Table 1. In order to find out whether the soil already contained the nitrogen fixing bacteria, one flat was left unfertilized and planted with soybean seed previously treated with a 0.1 percent solution of bichloride of mercury.

Observations were made on the germination of the seed and on the formation of nodules upon the roots of the seedlings. The percentage of germination was determined by counting the number of plants which appeared above ground. The effect of the fertilizer materials on bacterial development was studied by counting the nodules which developed on the roots of the plants after the soil

[1] Contribution from the Agricultural Experiment Station of the Virginia Polytechnic Institute, Blackburg, Va. Received for publication, March 20, 1922.

[2] Agronomist and Associate Agronomist, respectively.

was carefully removed from the roots by washing with water. The counts were made at the end of thirty and forty days. One half of the plants were used for the first count, and the remaining half for the last count.

RESULTS.

The results secured are shown in Table 1.

TABLE 1.— *The effect of fertilizers on the germination and bacterial development of inoculated soybean seed.*

Amount of fertilizers applied per acre.	Germination. Number of plants.	Germination. Per-centage.	Number of Nodules Formed. First count.	Number of Nodules Formed. Second count.	Number of Nodules Formed. Average count.
Acid phosphate, 200 lbs.	13	93	16	8	12
Acid phosphate, 300 lbs.	13	93	6	8	7
Acid phosphate, 400 lbs.	12	86	9	5	7
Check	14	100	11	9	10
Muriate of potash, 100 lbs.	14	100	10	14	12
Sulphate of potash, 100 lbs.	14	100	14	12	13
Nitrate of soda, 100 lbs.	14	100	5	7	6
Ammonium sulphate, 100 lbs.	14	100	10	6	8
Dried blood, 100 lbs.	14	100	8	8	8
Check	14	100	11	11	11
Basic slag, 300 lbs.	13	93	11	15	13

The soybean seed treated with bichloride of mercury and planted in the unfertilized soil gave a germination of 93 percent and none of the plants produced showed any nodule development. These results indicate the condition of the soil was favorable to the germination of soybean seed and that the soil did not contain the soybean organism. In view of these results it may be assumed, that if the nodule development on the roots of plants is decreased on certain of the fertilizer plats, the decrease was due to the fertilizer applied.

It may be seen from Table 1 that the fertilizers and the rates of applications used are the ones generally employed in ordinary farm practice. The acid phosphate used contained 16 percent available P_2O_5 and the basis slag contained 18 percent available P_2O_5.

The seed planted in the two check plats germinated 100 percent. If any of the fertilizers used have had an injurious effect on germination, the percentage of germination should be significantly lower than 100 percent. A glance at the table will show that none of fertilizers at the rate applied decreased germination to any appreciable extent. These results are in accord with those previously secured by the authors[1] on a sandy loam soil. However, it was

[1] HUTCHESON, T. B., and WOLFE, T. K. *The effect of fertilizers on the germination of seeds.* Va. Agr. Expt. Sta. Ann. Rept. 1918–1919, 33–37.

found in the previous investigation that fertilizers had a more deleterious effect on the germination of soybean seed on a silt loam than on a sandy loam soil. The injurious effect of fertilizers on germination of soybean seed was much less when the fertilizers were broadcasted and worked in the soil before the seed were planted, than when the fertilizers were distributed in the row and the seed placed in direct contact with the fertilizers.

The average number of nodules developed in the plants of one check was ten, while eleven was found on the plants of the other check. The number of nodules produced on the plants grown under the different fertilizer treatments were not markedly less than those found on the roots of the plants grown in the check flats. These results indicate that at the rate these fertilizers were used no pronounced injurious effect was produced on the bacterial development of inoculated soybean seed.

The results secured on this investigation may have been entirely different had the seed been mixed with the fertilizers and allowed to remain several days before planting. In this experiment the fertilizers were applied in the row and the seed planted and covered with soil immediately. Soil type has also been found by the authors [2] to affect the influence of fertilizers on the germination of seed.

The results indicate that the fertilizers, at the rate used in this experiment, when applied to a sandy loam soil in direct contact with soybean seed, did not have any appreciable detrimental effect on the germination of the seed or on the development of nodules on the roots of the plants.

AGRONOMIC AFFAIRS.

Summer Conference of New England Agronomists

Under the auspices of the New England section of the American Society of Agronomy and in cooperation with the Maine Agricultural Experiment Station and Aroostook County Farm Bureau, some thirty agronomists, pathologists, and others interested in problems of potato production spent three days, August 8–10, 1922, in Aroostook County, Maine, inspecting potato fields and discussing problems of certification and production. The following program was rendered:

Aug. 8th and 9th.— Important features of potato culture in Aroostook County — En route Annual Farm Bureau Inspection Trip. County Agent Edward W. Morton.

[2] Loc. cit.

Aug. 8th, 8:00 P. M.— Fort Fairfield.

What purchasers expect in the way of certified potato seed. Discussion led by Prof. J. S. Owens of Connecticut, County Agent J. H. Putnam of Massachusetts, and R. C. Parker, formerly County Agent on Long Island.

Aug. 9th, 8:00 P. M.— Presque Isle.

Certification of seed stock in Maine. E. L. Newdick, Maine State Department of Agriculture.

Certification in other states —

New York, Dr. M. F. Barrus;
New Hampshire, Dr. O. R. Butler; *
Vermont, Dr. E. Van Alstine.

Potato Diseases and their Control. Director W. J. Morse, Maine Agricultural Experiment Station and Dr. D. Folsom, Presque Isle Substation.

Aug. 10th, 9:00 A. M.—Inspection of experimental work on potato diseases. Drs. D. Folsom and E. S. Schultz, Presque Isle Substation.

Inspection of triangle fertilizer experimental fields. Drs. Oswald Schreiner and B. E. Brown.

Fertilizer and soil type relationship in Aroostook County. Dr. Oswald Schreiner. Bureau Plant Industry, Washington, D. C.

Necessary grades of mixed fertilizer for New England. Director S. B. Haskell, Massachusetts Agricultural Experiment Station.

A. B. BEAUMONT,
Secretary.

* Presented by Director J. C. Kendall.

BOTANICAL ABSTRACTS TO INDIVIDUALS FOR $5 THE YEAR

The price per volume of *Botanical Abstracts* (12 months with annual index) will be reduced to $5 *net*, providing 1,000 new, individual subscribers are secured. Former subscribers who dropped out before volume 9 are considered "new." This rate applies only to individuals who are located at a subscribing institution or who present evidence that their's is a *bona fide*, personal subscription.

The price of *Botanical Abstracts* volume 12 (January to December, 1923) to institutions, departments, officers, libraries, agents, etc., is $10 net.

If you have not been personally solicited, please enter your order on a 3 x 5 card, ready for filing, using the following form.

[on 3 x 5 card]

Name (as used in business)
Address (where to send the journal) } Please print.

I agree to subscribe for Botanical Abstracts at $5 *net*, the year, providing 999 others subscribe and thus make this offer possible.

Receipt of invoice for volume 12 at $5 *net*, payable on or before January 15, 1923, will be accepted as notice that the quota has been reached.

My institution is..............................

I am a member of....................................Society.

Postage to Canada, $0.40; to other Countries, $0.80.

All orders must be in the hands of the Business Manager, of Botanical Abstracts, College of Agriculture, Ithaca, New York, on or before November 1, 1922.

ANNUAL MEETING OF THE SOCIETY

The annual meeting of the American Society of Agronomy will be held in Washington, D. C., on Monday and Tuesday, November 20 and 21, 1922. All sessions will be held in the New Ebbett Hotel, 14th and F streets N. W. Programs will be mailed to members by the Secretary a few days in advance of the meeting.

JOURNAL

OF THE

American Society of Agronomy

VOL. 14 NOVEMBER, 1922 No. 8

THE EFFECTS OF SELF-FERTILIZATION IN TIMOTHY.[1]

H. K. HAYES AND H. D. BARKER.[2]

Studies carried on both in the United States and in foreign countries, notably Sweden, have demonstrated the fact that timothy may be improved by the selection and isolation of the more desirable strains. As timothy is normally a cross-fertilized plant, the practical improvement of commercial varieties is somewhat more difficult than with self-fertilized crops. For this reason the greater part of the commercial seed now used in the United States is of the ordinary unselected sort.

Webber, *et al* (4[3]) suggested the use of self-fertilized seed as a means of testing the transmitting ability of clonal lines. The method used to obtain self-fertilized seed as recommended by Webber, was to cover a group of about a dozen heads with a twelve-pound Manila paper bag just before blooming began. The heads were then shaken thoroughly each morning during the blooming period to insure the distribution of pollen over the pistils. Studies carried on at Minnesota have shown that some timothy plants are highly self-sterile while others are highly self-fertile. Since there is little available information regarding this question and as a knowledge of the mode of reproduction of a crop is essential to the breeder, it seemed worth while to present the results obtained.

Frandsen (1) compared the percentage of seed set under the following conditions: self-fertilization, cross-fertilization, and free-

[1] Published with the approval of the Director as paper No. 332, Journal Series of the Minnesota Agricultural Experiment Station, St. Paul, Minn. Received for publication, June 29, 1922.

[2] Head of Section of Plant Breeding, Division of Agronomy and Farm Management and Assistant Pathologist, Division of Plant Pathology and Botany, respectively.

[3] Reference by number is to "Literature cited," p. 293.

flowering. The following data give a comparison of timothy and brome grass as reported by Frandsen:

TABLE 1.—*Percentage of seed obtained by self-fertilization in timothy and brome grass.*

Species.	Percentage of seeds set: Self-fertilizing.	Cross-fertilizing	Free-flowering.
Phleum pratense	0.8–8.5	52.0	91.3
Bromus arvensis	66.6–80.0	80.4	77.2–89.2

Apparently timothy is highly self-sterile, while brome grass is apparently self-fertile.

THE MINNESOTA STUDIES.

In a preliminary study, heads of approximately fifty individual timothy plants were used. One or more heads were first covered with glassine bags which were about 6 by 2 inches in length and width, respectively. A Manilla-paper bag was then used to protect the glassine bags from heavy winds and rains. Only one or two seeds were obtained from these fifty plants.

A number of individual plants were then selected and 25 bulblets from each propagated in the greenhouse, the various clonal lines being isolated from each other by means of cheese cloth partitions. Three plants from each of several of the lines were also placed in isolated groups in the small grain nursery at some distance from other timothy plants, only those plants of the same clonal line being placed together. The amount of seed set under these various conditions gives a fairly accurate indication of the fruitfulness of the particular clonal line. As all lines produced numerous heads the differences observed and shown in Table 2 seem most reasonably to be attributed to genetic differences in the ability to produce self-fertilized seed.

In general, there is a marked similarity in the percentage of seeds obtained from a clonal line in the greenhouse and in isolated field plots. The first three clonal lines, T30–30–9, T30–30–21, and T31–64–1, produced a fair amount of seed both in the greenhouse and in the field. Line T31–97–11 is rather highly fruitful in all tests; while lines T32–65–14, T32–32–30, and T1–1–26, are apparently highly self-sterile. Seed of the various self-fertilized lines was planted in the greenhouse in the spring of 1922, the plants being carefully spaced about one inch apart. As shown in Table 3, several of these clonal lines produced a percentage of albino seedlings.

TABLE 2.— *Number of seeds obtained from isolated clonal lines in the greenhouse and from the same clonal lines in isolated field plots.*

Clonal line.	Greenhouse test. Number of seeds, 1919–20.	Greenhouse test. Number of seeds, 1920–21.	Isolated field plot. Number of seeds, 1921.
T30–30–9	56	202	208
T30–30–21	54	37	208
T31–64–1	11	73	208
T31–97–11	331	231	495
T32–65–14	6	0	0
T32–32–30	4	0	15
T1–1–26	1	2	0
T31–31–22	2	0	..
T32–98–24	1	25	..
T32–98–27	1	15	..

TABLE 3.— *Albino seedlings obtained from self-fertilized timothy seed.*

Clonal line.	Number of seeds planted.	Number which failed to germinate.	Number of albinos	Source of seed.
T30–30–9	202	12	0	Greenhouse
	208	26	0	Field
T30–30–21	37	1	5	Greenhouse
	208	4	..	Field
T30–63–23	104	6	1	Greenhouse
T31–31–5	104	6	0	Greenhouse
T31–64–1	73	3	1	Greenhouse
	208	18	4	Field
T31–97–11	208	9	11	Greenhouse
	203	12	8	Field
T31–97–18	84	0	0	Greenhouse
T32–32–30	16	2	0	Field
T32–65–29	7	1	0	Greenhouse
T32–98–24	22	4	1	Greenhouse
T32–98–27	21	0	0	Greenhouse
T1–1–26	2	0	0	Greenhouse

Probably all investigators who have practiced self-fertilization in corn have observed chlorophyll-deficient seedlings. The frequency with which they are obtained is of interest in relation to the frequency of the occurrence of albinotic timothy seedlings. Lindstrom (3, 4) has worked out the genetic relations of the four most common types — yellow, white, virescent-yellow, and virescent-white — which appear in self-fertilized lines of corn. Perhaps their frequency has not been generally appreciated by plant breeders although Hutcheson (2) has reported a test of 1872 self-pollinated ears which were grown under greenhouse conditions. Approximately 36 percent of these ears gave seedling lethals in a part of their progeny, while

a little over 28 percent gave chlorophyll deficiencies which were observable in the seedling state.

Recently, the frequency of chlorophyll seedling deficiencies has been observed in several standard varieties of corn at Minnesota, as shown in Table 4.

TABLE 4.—*Seedling chlorophyll-deficient types observed in normally pollinated and first-year selfed strains of standard Minnesota corn varieties.*

Variety.	Type of pollination.	Number of plants.	Number of chlorophyll deficient plants.
Minnesota No. 13	Normal	1,305	9
Rustler	Normal	880	2
Minnesota No. 23	Normal	792	2
Northwestern Dent	Normal	616	3
King Phillip	Normal	792	1
Longfellow	Normal	880	2
		Number of strains.	Number of strains with chlorophyll-deficient seedlings
Minnesota No. 13	1 yr. selfed	29	17
Rustler	1 yr. selfed	6	3
Northwest Dent	1 yr. selfed	4	2

As corn is largely cross-pollinated the percentage of seedling lethals obtained by the use of normally pollinated seed is very small. The thirty-seven first-year selfed lines were from plants which appeared vigorous and of desirable type as observed in the field. Of these thirty-seven strains twenty-two gave seedling lethals.

Although the number of timothy first-year self-fertilized lines which were grown in the greenhouse is very small the results indicate that chlorophyll-deficient types appear as frequently in self-fertilized timothy, as in corn, since five lines out of a total of twelve tested gave some albino seedlings. Witte (6) has reported a timothy plant which when selfed gave progeny which produced degenerate pistils and ovules. Apparently, therefore, self-fertilization in timothy, as in corn, is a logical means of freeing the strain of undesirable recessive characters.

SUMMARY.

Self-fertilized clonal lines of timothy differed widely. This was probably due to genetic causes as there was marked correlation between the percentage of seed set under various conditions.

Five out of eleven first-year self-fertilized strains gave some albino seedlings in their progeny.

LITERATURE CITED.

1. FRANDSEN, H. N. Die Befruchtungsverhältnisse bei Gras und Klee in ihre Beziehung zur Zuchtung. Zeitschr. für Pflanzenzucht, 1:1–31. 1917. Abstract by Ubisch in Bot. Centralblatt. 137, p. 211. 1918.

2. HUTCHINSON, C. B. Heritable variations in maize. *In* Jour. Amer. Soc. Agron. 14:73–78. 1922.

3. LINDSTROM, E. W. Chlorophyll inheritance in maize. N. Y. (Cornell) Agr. Exp. Sta. Mem. 13:3–68. 1918.

4. ———— Concerning the inheritance of green and yellow pigments in maize seedlings. *In* Genetics 6:91–110. 1921.

5. WEBBER, H. J., HUNT, T. F., GILMORE, J. W., CLARK, C. F., and FRASER, S. The production of new and improved varieties of timothy. N. Y. (Cornell) Agr. Exp. Sta. Bul. 313. 1912.

6. WITTE, HERNFRID. Über weibliche Sterilität beim Timotheegras (Phleum pratense L.) und ihre Erblichkeit. Svensk Botanisk Tidskrift 13:23–42 2 Abt. 1919. Abstract by Fruwirth in Zeitschr. Ind. Abstamm. u. Vererb. 28:248. 1922.

THE INTERPRETATION OF MECHANICAL ANALYSIS OF SOILS AS AFFECTED BY SOIL COLLOIDS.[1]

R. O. E. DAVIS.[2]

OBJECT OF MECHANICAL ANALYSIS.

The mechanical analysis of the soil is employed to determine quantitively the relative amounts of the different sized mineral particles making up the soil.[3] The relative amount of these various sized grains has an important bearing on the character of the soil and from the results of the analysis the soil is classified as a "sand," "loam," "clay," etc. Closely related to the mechanical composition of the soil are the waterholding capacity, the power of capillary attraction for water, drainage, ease of tillage, and productivity. The limits set for the definition of the group sizes are largely arbitrary, but are those which have been found to be most practical in operation. The limits adopted by the U. S. Bureau of Soils (2) are as follows: fine gravel 2 to 1 mm. in diameter; coarse sand 1 to .5 mm.; medium sand .5 to .25 mm.; fine sand .25 to .1 mm.; very fine sand .1 to .05 mm.; silt .05 to .005 mm.; clay less than .005 in diameter. The soil classification, based on the texture of the soil

[1] Contribution from Bureau of Soils, U. S. Department of Agriculture. Published by courtesy of the American Chemical Society; read at the Birmingham meeting, April 5, 1922. Revised for publication, June 16, 1922.

[2] Scientist in Charge of Soil Physical Investigations.

[3] Reference by number is to "Literature cited," p. 298.

and indicated by means of mechanical analyses, divides the soil into twelve different classes, as follows:

(a) Soils containing less than 20 percent of silt and clay;

(1) "Coarse sand," over 25 percent gravel and coarse sand, and less than 50 percent of any other grade.

(2) "Sand," more than 25 percent fine gravel, coarse and medium sand, and less than 50 percent of fine sand.

(3) "Fine sand," more than 50 percent of fine sand, or less than 25 percent of fine gravel, coarse and medium sand.

(4) "Very fine sand," over 50 percent of very fine sand.

(b) Soils containing 20 to 50 percent of silt and clay;

(5) "Sandy loam," over 25 percent of fine gravel, coarse and medium sand.

(6) "Fine sandy loam," over 50 percent of fine sand, or less than 25 percent of fine gravel, coarse and medium sand.

(7) "Sandy clay," 20 percent of silt.

(c) Soils containing more than 50 percent of silt and clay;

(8) "Loam," less than 20 percent of clay and less than 50 percent of silt.

(9) "Silt loam," less than 20 per cent of clay and more than 50 percent of silt.

(10) "Clay loam," 20 to 30 percent of clay and less than 50 percent of silt.

(11) "Sandy clay loam," 20 to 30 percent of clay and over 50 percent of silt.

(12) "Clay," more than 30 percent of clay material.

The classification of soils in other countries differs somewhat from that adopted by the U. S. Bureau of Soils, mainly because of the adoption by them of different limits for the various groups of material, determined through mechanical analysis.

EFFORTS OF DEFLOCCULATION.

In the various methods of making mechanical analyses the effort is made to bring about deflocculation of fine particles in the soil before analysis is attempted. When collected in the field the sample of soil is generally in a more or less moist condition, but usually comes into the laboratory in an air dry state. In this condition, there have been formed hard lumps which must be broken down in order to determine the grain composition, and the various methods of preparation attempt to bring about not only a breaking down of the lumps but a deflocculation of the fine material of the silt and clay groups. The different methods recommended for deflocculation are: treatment with acid, rubbing with a rubber pestle, and shaking with water or with water and an alkali.

The centrifuge method of analysis was worked out in the U. S. Bureau of Soils and has been in use by its workers in analyzing

thousands of samples of soils. As prelim[illegible] soil is suspended in water with a few drops of ammonia and shaken for seven hours or more in a shaking machine. Experiments by Briggs, Martin and Pearce (3) have shown that this means of deflocculation gives better results than any other, especially in handling a large number of samples, and that while deflocculation was not quite complete after this length of time the continued shaking for a longer period produced only slight changes. It is quite evident that for the proper separation of the grain sizes a complete deflocculation is desirable, as otherwise small aggregates of material may be classed as belonging to a group with size limits considerably above that to which the individual deflocculated material would belong.

COLLOID CONTENT OF SOILS.

It has long been appreciated that soils contain material of a colloidal nature but it was believed that truly colloidal material was of a small amount and rather insignificant, and that after the treatment described as used in the Bureau of Soils, it would be obtained in the clay group in a mechanical analysis. Various investigators have made efforts to separate the colloidal material, itself, in the soil and it has been believed by Schloesing (4) and later investigators, that the amount ranges from 0.5 to 2 percent in what is termed a clay soil, although by the Atterberg (5) and Williams (6) methods of mechanical analysis a large amount of material is secured, which must be largely colloidal. The method usually used for extraction of the colloid is that of shaking with water and separation through subsidence, allowing the larger particles to settle and the colloidal particles to be withdrawn in the supernatant liquid. The workers in the U. S. Bureau of Soils have been investigating this colloidal content for several years and have worked out a method for extracting samples in which large amounts of soil are shaken up with water and the suspension run through a high speed centrifuge which generates a force of about 17,000 gravity, acting on the average particle. The liquid passing through this centrifuge contains a disperse material which is then collected by suction on a Pasteur-Chamberlain filter. By repeated extractions through rubbing and shaking with water, amounting to about forty operations, it has been shown that amounts perhaps as high as 50 percent of colloidal material are contained in some of the clay soils. This colloid, if separated in this way, may be obtained in the disperse system. The particles show under the ultra-microscope the true Brownian movement and the material when dried is of a horny, resinous character and is highly absorptive for water, dyes, and gases.

COLLOIDAL CONTENT OF SEPARATES.

A sample of soil which on mechanical analysis was shown to contain 51.4 percent of silt and 13.1 percent of clay was tested for its colloidal content. These tests showed that little colloid existed in the sand groups, and that the clay group was made up almost entirely of aggregates of colloidal material while the silt contained about 18 percent of colloidal aggregates.

SEPARATION OF COLLOIDS BY ATTRITION.

It has been indicated by absorption tests that the clay group was made up largely of colloid material, but continued shaking with water did not break up the coagulated particles, or in other words, these particles, made up of groups of agglomerated material, formed into aggregates which were not further broken down by simply shaking with water. It was undertaken to separate the clay group by rubbing and subsidence and it was found that by repeated rubbing with a rubber pestle that some colloid was separated on each treatment and that after repeated treatments (18 to 40 times) there remained a small portion of the original fraction that subsided more quickly, that showed under the microscope angular mineral particles. The bulkier portion of the material appeared identical with the ultra-clay, as the colloidal portion has been called. The angular portion did not exhibit the characteristic properties of the colloidal portion.

That the mechanical analysis as carried out does not necessarily give the true relationship of the mineral particle sizes has been shown in another way. A number of samples of deep sea bottoms were submitted to the Bureau of Soils for mechanical analysis by Dr. T. W. Vaughan of the U. S. Geological Survey. These samples appeared, from the separations made, to contain considerable portions of material falling within the sand and silt groups. However, the material indicated by the analysis as belonging to sand or silt groups could be easily crushed with the finger, leaving on a sheet of paper a black streak. These particles were mere agglomerations of very fine material that were not deflocculated by the treatment of shaking with water. Tests indicated that these samples, although they would be classed by mechanical analysis as loams or sandy loams, were 80–90 percent colloidal with sufficient material of shell particles, as shown by the carbonate test, to furnish the remainder.

It has often been pointed out that it is very difficult to make an accurate mechanical analysis and that different analysts frequently disagree in their results. The explanation seems to lie in the fact that the soil aggregates are not broken up to the same extent and

can entirely defloccul . .
in part, at least, the relative proportion

DESIRABILITY OF EXPRESSING THE COLLOID CONTENT.

The clay part of the soil has long been regarded by soil investigators as the most active part of the soil. Its absorptive action has been believed to be both physical and chemical (7). It has been shown that this most active portion of the soil is very absorptive and that the absorptive part is probably largely the soil colloid and very little the unaltered mineral particles. Work in this Bureau indicates that this colloidal soil material is probably double silicates of iron and alumina. It is plain from the properties exhibited by this material that the soil solution relations, water retention of soil, and moisture movement all depend very largely on the amount and character of the colloid, also that such physical properties as percolation, clodding, tilth, shrinkage of the soil are influenced by the quantity and distribution of the colloid. This colloid material probably is the plastic material in the soil. In testing the cementing properties of the colloid, or ultra-clay, separated from several soils, its strength when dried was determined by some experiments carried out in our laboratory. The crushing strength of briquettes containing the colloid were compared with similar ones using Portland cement. The briquettes were 25 x 25 mm. of cylindrical shape. Made up with the same sand, 10 percent cement gave a crushing strength of 19 kilos, 10 percent of Cecil clay colloid gave a crushing strength of 122 kilos, and with 10 percent of Susquehanna clay colloid, 96 kilos. A similar series with quartz flour gave, cement, 112 kilos; Cecil clay colloid, 304 kilos; Susquehanna clay colloid, 207 kilos.

POSSIBLE MODIFICATION OF ANALYSIS.

From the foregoing considerations and the experimental results obtained it appears that the mechanical analysis as carried out does not furnish us with the true meaning as to the quantitative distribution of the various sized mineral particles in the soil and that it is particularly desirable to determine the colloid content and its distribution. The different groups of mineral particles, and especially the slit and clay groups, are made up in part of colloidal material, and it is possible that a method may be worked out for determining the amount of colloid in the soil and in the silt and clay groups. The process of rubbing a soil sample in water with a rubber pestle and decanting, while possible, is too laborious and tedious to be employed on a large number of samples in a routine way. Work in

progress indicates that a determination of the colloid by the absorption of water vapor may give the desired information. The major portion of the colloidal material is contained in the silt and clay groups, so that by determining the colloid in the soil and in these two groups, information might be obtained that would show the amount and distribution of this colloid, and as a result the correction that should be applied to the mechanical analysis to show the proper amounts of mineral particles in those groups.

LITERATURE CITED.

1. Various methods of mechanical analysis are described in King, F. H., Physics of agriculture (1907); Wiley, H. W., Principles and practice of agriculturcl analysis (1906); Mosier and Gustafson, Soil physics (1917); U. S. Dept. Agr. Bur. of Soils Bul. 24 (1904) and 84 (1912); Atterberg, Intern. Mitt. f. Bodenkunde 1:7 (1911); Williams, Forsch d. Gebiet d. Agrik-Physik 18:225 (1895).
2. Fletcher, C. C., and Bryan, H. Modification of the method of mechanical soil analysis. U. S. Dept. Agr. Bur. Soils Bul. 84 (1912).
3. Briggs, L. J., Martin, F. O. and Pearce, J. R. Centrifugal method of mechanical soil analysis. U. S. Dept. Agr. Bur. of Soils Bul. 24 (1904).
4. Schloesing, T. Compt. Rend. 78:1276. (1874).
5. Atterberg, A. Mechanische bodenanalyse. II Internationale Agrogeologen-konferenz. Stockholm (1910).
6. Williams, W. R. Mechan. bodenanalyse. Forsch d. Gebiet d. Agrikultur-Physik (Wollny) 18:225–350. (1895.)
7. Liebig, J. Natural laws of húsbandry. J. Roy. Agric. Soc. 11:313. (1850); Ibid 13:123. (1852).

SCARIFICATION AS IT AFFECTS LONGEVITY OF ALFALFA SEED.[1]

L. F. Graber.[2]

The value of scarification for the elimination of hard seeds in alfalfa and clovers has met with a wide-spread appreciation. The Ames Hulling and Scarifying machine is being used on a commercial basis in the seed industry. Evidence of its value is abundant and striking. The immediate germination of commercial lots of alfalfa seed containing 25 percent hard seeds has frequently been found to increase from 70 percent to 90 percent or better, following scarification. With sweet clover, which often contains a higher percentage of hard seeds, the results have been even more pronounced, as Table 1 indicates. Furthermore, there appears to

[1] Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication.

[2] Professor of Agronomy.

be a benefit from scarification that is not entirely made evident by the ordinary six day germination test.

TABLE I.— *Effect of scarification on the immediate germination of legume seeds containing more than ten percent hard seeds.*

Kind of seed.	Percent of germination. Before scarification. Immediate.	Before scarification. Hard seed.	After scarification. Immediate.	After scarification. Hard seed.
Grimm alfalfa	70	25	91	Not given
Grimm alfalfa	77	23	94	Not given
Hubam clover	69	34	92	2
Yellow blossom sweet clover	28	60	80	5

In an experiment conducted by the Agronomy Department of the Wisconsin Station, alfalfa seeds still remaining hard after having been in the germinators for six days were removed for further test. One hundred of these hard seeds were obtained from scarified samples and one hundred from the same lots of seed which had not been scarified. These seeds were sown separately and at a uniform depth in a greenhouse flat of fertile loam soil. The flat was placed in the open field on April 6, 1919, where it would be exposed to normal spring weather to avoid the "damping off" fungus difficulties of the greenhouse. After a three-week period, the one hundred seeds still remaining hard in the scarified alfalfa produced forty-six alfalfa seedlings (46 percent) compared with twenty-five seedlings (25 percent) for the hard seeds which came from the unscarified alfalfa. While scarification will not necessarily cause a complete elimination of all hard seeds, as indicated by a six day germination test, it is significant that scarified seeds still remaining hard had been scratched sufficiently to result in the production of nearly twice as many seedlings as obtained under similar conditions with hard seeds selected from unscarified samples.

While these results indicate the effectiveness of scarification for the improvement of immediate germination, its influence on the longevity of alfalfa seed appears to be deleterious in character.

An experiment was begun in September, 1921, to test the effect of age on the germination of forty-four samples of unscarified alfalfa seed which had been stored for periods of from two to twelve years in a cool dry basement. The original germination of the lots was known in all cases but one and ranged from 91 to 95 per cent. The fact that all this seed had been used in field tests and produced excellent stands of alfalfa indicates that the germination must have

been very satisfactory, even in the case of the 6 year old samples where the original germination had not been recorded.

TABLE 2.— *Effect of age on the germination of samples of alfalfa seed stored in a cool dry place for two to twelve years.*

No. of samples.	Age in years.	Original germination.	Present germination.
		Per cent.	*Per cent.*
3	10 and 12	94.5	47.0
6	9	92.0	54.2
8	8	91.1	63.9
13	7	91.3	69.6
5	6	Not given	65.6
5	4	95.7	78.8
4	2	93.0	87.5

Carefully conducted tests [3] showed a fairly proportionate decrease in germination with age (Table 2), which ranged from 87.5 percent for the 2-year old lots to 47.0 percent for the 10 and 12-year old seed. In conducting these tests, one lot of seed (not included in Table 2) showed a very rapid deterioration in germination from 89 percent in 1919 to 32 percent in 1922. In three years this lot of alfalfa (Sample No. 597) decreased in germination more than thirty other samples stored under the same conditions from 7 to 12 years. This wide discrepancy resulted in an examination of the records concerning lot No. 597, which revealed that the seed had been used by the state alfalfa growers' association for demonstration purposes. It was harvested in Montana in the fall of 1917, but was not scarified until early in the spring of 1919. Fortunately, a sample of this same lot of seed, taken before scarification for a germination test, was located—the original germination being 85 percent with 10 percent hard seeds in addition. This unscarified seed was tested in April, 1922, and gave an immediate germination of 70 percent, a decided contrast with the same seed scarified three years previous, which only germinated 32 percent.

This led to the assembling of all the sample lots of seed which were used by the state alfalfa growers' association, of which scarified and unscarified portions and original germination tests were available. Four additional lots were found answering these requirements, varying in age from two to three years. Two lots, Nos. 729 and 567, three and four years old, respectively, had been scarified; but the unscarified portions of this seed were not located and for this reason, are not included in the tabular data. The samples were

[3] Special credit is due J. T. Omernik, graduate student, who made the final viability tests.

all carefully tested with the rather surprising comparative results indicated in Table 3.

TABLE 3.—*Effect of scarification on the longevity of alfalfa seeds stored in a cool dry place.*

Sample no.	Variety.	Age of seed in yrs.	Seed treatment.[1]	Percent of germination. Original. Immediate.	Original. Hard seeds.	Final. Immediate.	Final. Hard seeds.
597	Baltic	4½	None	85	10	70	10
597	Baltic	[2] 4½	Scarified	89	7	32	0
654	Grimm	3	None	66	[3]	74	4
654	Grimm	3	Scarified	82	[3]	29	0
655	Grimm	3	None	62	[3]	78	4
655	Grimm	3	Scarified	79	[3]	31	1
847	Grimm	3	None	70	25	81	10
847	Grimm	3	Scarified	91	[3]	40	0
1005	Grimm	2	None	70	22	69	14
1005	Grimm	2	Scarified	91	[3]	68	4
Average immediate germination of unscarified samples				70.6%		74.4%	
Average immediate germination of scarified samples				86.4%		40.0%	

The scarified portions of the five lots of seed deteriorated rapidly in germination from an average of 86.4 percent at the time of scarification to 40.0 percent at the end of two and three years. The unscarified seed, on the other hand, gave an average increase in immediate germination, at the end of the same periods of time, of 3.8 percent. This can be accounted for by the high percentages of hard seeds which the samples originally contained. It appears that hard seeds, which are practically always viable, gradually soften with age, become permeable, and germinate readily. Comparing the original germination of the treated and untreated lots Nos. 654 and 655, it is safe to say, that the unscarified portions each contained at least sixteen percent hard seeds at the time the test was made. At the end of three years only four percent hard seeds remained, even though these lots were not scarified. Likewise, with the remaining lots, there is a prominent reduction in the percentage of hard seeds with age, except in the case of the unscarified Baltic.

Two scarified lots of seed (previously mentioned), Nos. 729 and 567 decreased in germination when three and four years old to 51 percent and 27 percent from their original viability of 94 percent and 95 percent, respectively.

[1] Unless otherwise indicated, the seed was scarified within five months after harvest.

[2] Scarified when one and one-half years old, at which time original germination tests were made.

[3] Percent hard seeds not recorded in original test.

These results are very pronounced, and while the number of samples tested in this experiment are not numerous, the data indicates quite clearly that scarification undoubtedly exposes alfalfa seed to factors which cause a far more rapid decrease in germination than normally obtains with the untreated seed. From a practical standpoint scarification is often essential for improvement of the immedite germination of some legume seeds, but where these seeds are to be stored for more than one year, as sometimes obtains in the seed industry and frequently in experimental work, the wisdom of delaying this treatment until a few months before seeding is quite evident.

DETERMINATION OF THE SWELLING COEFFICIENT OF DRY SOILS WHEN WETTED.[1]

A. E. VINSON and C. N. CATLIN.[2]

No method of determining accurately a physical constant for the swelling of dry soil when wetted, comparable to the hygroscopic water content or to the moisture equivalent, was known to the writers when the method described in this paper was worked out. Tempany [3] has described a method of measuring the shrinkage of soils on drying. From the data obtained by his method, he has estimated the amount of colloids present and judged soils as to their adaptability to certain crops. It seemed that the swelling property of soils might be correlated with other soil properties, if it could be determined with reasonable accuracy. Investigations made in our laboratory on a limited number of soil types indicate that the amount of swelling on wetting is a constant for any particular soil which is susceptible of as exact determination by a strictly empirical method as other physical soil constants.

The purpose of this paper is to make available a new method rather than to present any results that have been obtained by its use. Study of a few soil types shows a certain correlation between the swelling constant and the mechanical analysis, the moisture equivalent, and the hygroscopic moisture content, although there seems to be no fixed ratio. This fact gives added value to the new constant. It will probably be of value in investigating the influence of various soil treatments, such as liming and fertilizing, on the physical char-

[1] Contribution from the Department of Agricultural Chemistry, University of Arizona, Tucson, Ariz. Received for publication June 19, 1922.

[2] Professor and Associate Professor, respectively.

[3] Tempany, H. A., shrinkage in soils. Jour. Agric. Sci. 8:312. 1917.

acter of the soil, as well as a means of determining and recording accurately an important physical constant of soil in general.[4] The method may also be of service in investigating the expansion and contraction of road building material which contains silt and clay, and in studying the probable wet and dry volumes of consolidated river sediments. It is now being used in studying the correlation of the rate of percolation through alkaline soils with the swelling coefficient and the effect of chemical treatment on these properties; but the results are not ready for publication.

DETAILS OF THE METHOD

Preparation of sample.— The sample is sifted through a 2 mm sieve as for mechanical analysis, and dried over sulphuric acid. Drying at 100° C. may possibly change the swelling coefficient of certain soils.

Preparation of the soil disk.— Ten grams of the dried soil is placed in a cylindrical steel die having an opening about one inch in diameter, and is compressed under a hydraulic press at 30,000 to 35,000 pounds. It is essential to distribute the soil evenly over the bottom of the die, because the disk will not be of even density if the soil is heaped up in the center or against the side. The Buchner laboratory press is suitable for the purpose, and the pressure on this press should be held at 250 kilograms per square centimeter, as indicated by the gauge, for ten minutes. The die is then placed on a hollow cylinder or ring having an opening larger than the disk, and the disk forced out on the press. All soils thus far investigated gave firm, water-free disks with the exception of pure sand, which crumbles. Disks of soils that are very high in organic matter, such as muck, tend to split on the edges when released from the die. This is especially apt to be the case after the dies have become chafed. Frequently several trials are necessary to get perfect disks with such soils. Some soils are elastic and expand slightly when pressed from the die, which makes it difficult to press them into place in the expansion cup. All soils begin swelling at once, due to absorption of moisture from the air, consequently, the swelling must be measured soon after the disks are made. Attempts were made to determine the coefficient of swelling in moist air, but no consistent results could be obtained. There was also a tendency for the outside of the disk to split off, or for the disks to split in two.

The disks are calipered at once with a millimeter screw micrometer reading to one one-hundredth millimeter. It is convenient to support

[4] The writers will gladly determine the swelling constant on a few samples of recognized soil types from other states if accompanied by full information.

the micrometer in a vise or with [illegible] rette clamp. A thin cover-glass is placed between the disk and the jaws of the micrometer on each side to give a better face. Soils of fine texture would not need this, but sandy soils tend to rub off. The thickness of the two cover glasses is measured and deducted from the micrometer reading. The disks should be 5.5 to 6.25 mm in thickness.

The dies must be made with care, best out of tool steel, bored and case hardened, then ground true. Soft steel chafes badly and even wears to such an extent that the disks soon are too large to fit nicely into the swelling cup. The plunger must fit very snugly into the die; otherwise soil will work in between the plunger and the side of the die and stick the plunger. When the plunger is forced out, both die and plunger will be scored and practically ruined. This is especially likely to happen when pressures greater than those recommended are used. The die and swelling cups must be made to correspond, the cup being about one-sixty-fourth inch larger than the disk. Convenient dimensions for the die are four inches in height, with bore one inch in diameter. It may be difficult to grind the die exactly one inch in diameter, but a slight variation will make no appreciable difference in the swelling coefficient. The block should be large enough to give a firm bearing, at least three inches in diameter, and the plunger should be three-fourths to one inch longer than the die.

Measuring the swelling. The dry soil disks, immediately after calipering, are dropped into the brass swelling cup and placed in a convenient vessel on the MacDougal auxograph. The apparatus used in our experiments is illustrated in the accompanying plate. Sufficient water is added quickly and the disk allowed to swell without further disturbance. Maximum swelling takes place usually in 30 to 40 minutes, but some soils continue to swell much longer. The maximum magnified swelling is read off from the sheet of millimeter paper carried on the clock drum of the auxograph, then calculated to absolute swelling by the use of a suitable factor, depending on the length of the arm of the auxograph in use. The absolute swelling in mm of the disk in the vertical direction divided by its thickness gives the swelling coefficient.

The swelling cup should be about one inch deep on the inside, so that disks of soil having the greatest coefficient fill it about two-thirds full when maximum swelling is reached. The sides and bottom of the cup are one-eighth inch thick. The bottom is perforated with large holes so that only a substantial support remains; the sides are perforated with a large number of one-sixteenth inch holes especially close together near the bottom of the cup. The bottom of the cup

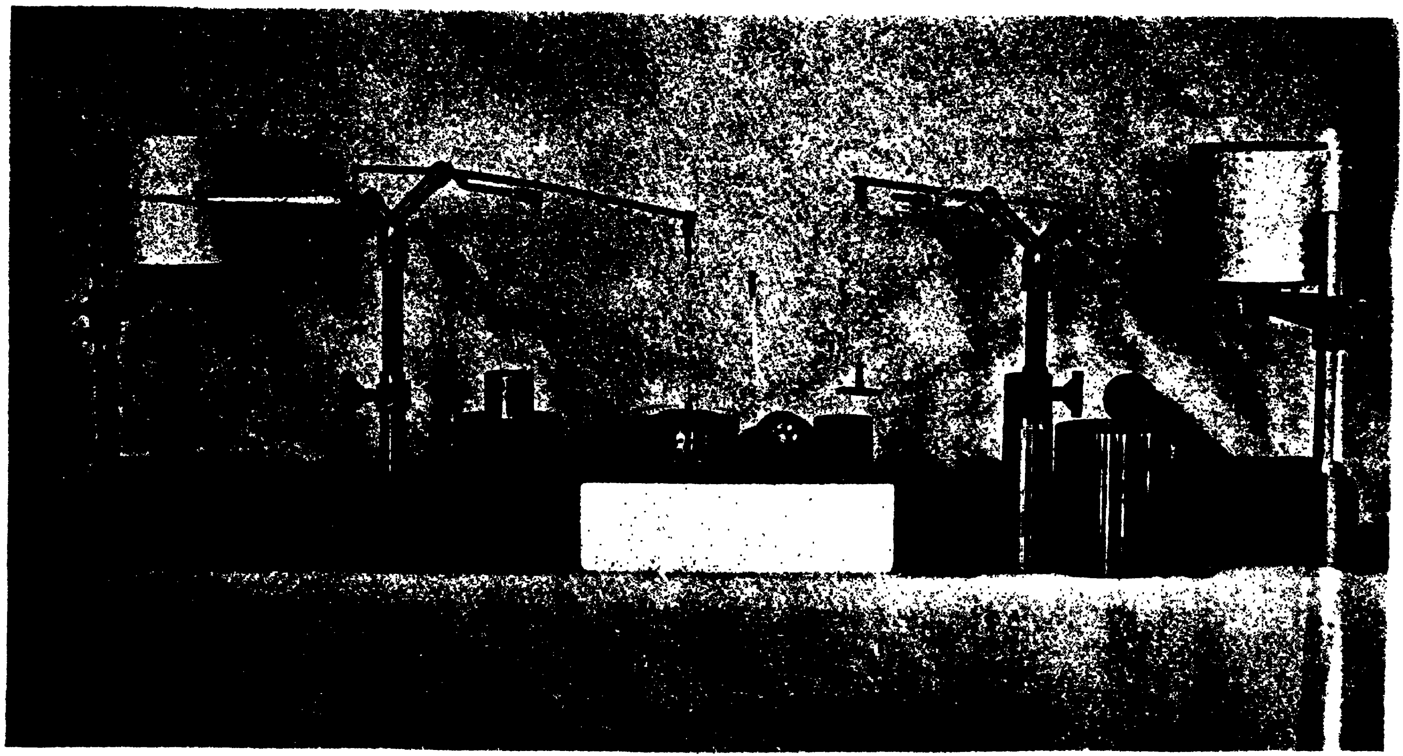


PLATE I. *Apparatus used for determination of swelling coefficient of soils.*

is covered with a close-fitting piece of circular, flattened brass gauze which supports the soil disk. A second similar brass gauze, which rests on the top of the soil disk, is carried on a fine glass rod attached to the arm of the auxograph. The pieces of flattened brass gauze are prepared by pressing circular disks of brass gauze in the die used for making the soil disks. Glass disks cannot be used, since they do not permit the escape of air bubbles, and, consequently, heave when the water comes in contact with the soil disk. The cup is mounted on three feet about one-quarter inch high, so as to allow ready access of water under the disk.

The water vessel may be made by carefully leveling a glass plate in softened paraffin in the bottom of a crystalizing dish. The bottom of the water vessel must be level as must also the firm support on which it rests.

The adjustment of the brass gauze attached to the auxograph arm requires much care, or satisfactory checks will not be obtained. The water vessel with the swelling cup and soil disk is brought under the auxograph and so adjusted that the gauze disk bears firmly on the soil disk at all points. The disk is pressed firmly but lightly on the soil disk and the pen set at zero on the millimeter paper. A light weight is placed on the arm of the auxograph to prevent the gauze disk from floating before it becomes wet when the water is added. Distilled water is then poured quickly into the water vessel almost to the top of the swelling cup and the weight removed instantly from the arm of the auxograph. Some soil will drop out through the perforations in the cup, but this does not affect the readings. The disk swells at first very rapidly, then slower and slower until the maximum swelling is reached, where it remains indefinitely if not disturbed. The wet, swollen disk will now be found in about the same condition as consolidated wet soil that has not been disturbed for a long time; that is, it corresponds to a fully swollen colloid. Occasional erratic results may be attributed to jarring the apparatus, slipping of the chain links or other parts of the auxograph, failure to adjust properly the upper gauze disk on the soil disk, the water vessel and swelling cup not being level, or failure of air bubbles to escape freely through the gauze disk. Results varying much from the average should be discarded.

The arm of the auxograph as designed by MacDougal gives a minimum magnification of ten. The variation in the swelling coefficient of different soils is much too great to permit their determination on this instrument without varying the thickness of the disk. Since the method is entirely empirical, it would be undesirable to vary the thickness of the disk materially, and our investigations indicated

that consistent results could not be obtained on the same soil by the use of disks of varying thickness. Attempts to dilute strongly swelling soils with sand so as to give the same thickness of disk also proved unsatisfactory. It is therefore best to have an arm on the auxograph twice the usual length so as to reduce the magnification to five in the case of soils whose swelling coefficient would throw the pen below the drum if the 1:10 magnification were used. The ratio between the movement of the gauze disk on the auxograph arm and of the pen may be calculated from the length of the levers, or, better, may be measured directly by means of the millimeter paper for the pen and the cathetometer for the disk.

The lever system of the auxograph is carefully balanced so that almost no pressure bears on the expanding soil disk.

ACCURACY OF THE METHOD

The following table gives a fair idea of the checks which may be obtained on the swelling of consecutive disks from the same dry sample of soil when the method is carried out carefully.

TABLE 1.—*Showing checks on the swelling of consecutive disks and the average swelling constant.*

Kind of soil.	Auxograph reading in millimeters.	Magnification of swelling.	Absolute swelling in mm	Average thickness of dry disk in mm	Swelling constant.
Calcareous gravelly loam	34.5	....	....	....	....
	34.0	....	....	....	....
	33.5	....	....	....	....
	35.5	....	....	....	....
	33.5	....	....	....	....
Average.............	34.2	1:10	3.42	5.7	60
Maricopa gravelly loam	43.0	....	....	....	....
	43.0	....	....	....	....
	43.0	....	....	....	....
	42.5	....	....	....	....
	43.0	....	....	....	....
Average.............	42.9	1:10	4.29	5.75	74.6
Silt and clay sediment from river.	51.0	....	....	....	....
	51.5	....	....	....	....
	51.0	....	....	....	....
Average.............	51.16	1:5	10.233	5.89	174
Muck................	54.0	....	....	....	....
	54.0	....	....	....	....
	53.5	....	....	....	....
	53.0	....	....	....	....
Average.............	53.62	1:5	10.72	5.91	181

COMPARISON WITH OTHER CONSTANTS

Table 2 shows the correlation between the mechanical analysis, the moisture equivalent as determined with the Briggs-McLean centrifuge, and the swelling coefficient.

TABLE 2— *Comparison of swelling coefficient with other constants.*

Mechanical analysis	Muck	Rillito clay	U. of A. sandy loam	Maricopa gravelly loam	Calcareous gravelly loam
Fine gravel	....	....	.4	2.3	3.6
Coarse sand	1.0	1.2	1.7	9.0	16.1
Medium sand	3.4	7.6	3.5	8.9	16.2
Fine sand	19.7	6.2	21.9	20.4	18.8
Very fine sand	19.6	7.5	45.4	39.7	25.5
Silt	25.7	21.5	11.3	7.6	10.6
Clay	30.3	55.1	15.8	9.7	6.0
Total	99.7	99.1	100.0	87.6	96.8
Loss on ignition	9.71	11.14	12.76	3.93	3.54
Moisture equivalent	33.0	34.8	8.0	9.0	7.2
Swelling coefficient	181.4	173.7	67.5	74.6	60.0

THE RATE OF SWELLING

Different soils show marked differences in the rate of swelling, and chemical treatment modifies this rate enormously. A calcareous, silty clay, deposited from the overflow of the Gila River, after partial neutralization of the calcium carbonate with acetic acid then drying gave nearly the same swelling coefficient as the untreated soil; but the treated soil required two hours to swell the same amount as shown by the untreated soil in five minutes. The study of the rate of swelling cannot be done advantageously with the clocks on the regular MacDougal auxograph, since these are set to give the drum one revolution in one or seven days. A clock giving one revolution of the drum in fifteen or twenty minutes will probably be found most suitable for the study of the rate of swelling. This phase of soil swelling has been little studied.

THE TEACHING OF SOILS.[1]

FIRMAN E. BEAR.[2]

A knowledge of the principles of chemistry, physics, geology and biology is fundamental to the study of soils. In their application they constitute soil science. The student learns in the chemical laboratory

[1] Contribution from the Department of Agricultural Chemistry and Soils, Ohio State University, Columbus, Ohio. Received for publication September 10, 1922.

[2] Professor.

that acids and alkalies neutralize each other. In the application of this principle he finds that the nitric acid produced in the decomposition of organic matter in the soil has its natural neutralizing agent in limestone. Physical science teaches among other things that if a glass tube is placed in a vertical position in a liquid there is usually an elevation but at times a depression of the liquid within the tube. In the application of this principle it is found that water tends to rise in the soil from lower levels to take the place of that lost by evaporation or transpiration from the surface. In the study of geology it is discovered that the original igneous rocks, through the action of weathering agents and of running water, go to form limestones, sandstones and shales. In the field the student learns that the soils resulting from the weathering and disintegration of these three types of rocks differ fundamentally in their natural productive capacity and the explanation soon becomes apparent. Among other things the biological laboratory offers opportunity for the study and classification of microscopic forms of plant life. The application of this in soils discloses the highly important fact that at least three species of micro-organisms are concerned with taking nitrogen from the air to be utilized by the growing crops and that without them the fields would soon be barren of vegetation.

Soil science can be taught by the chemist as a part of the general course in chemistry or as a specialized course following it. The chemist is quite as likely, however, to have his chief interest in some other application of chemistry such as engineering, medicine, pharmacy, metallurgy or animal nutrition as in the soil. In arranging his laboratory exercises and in directing the line of thought of his students the instructor chooses his illustrations usually from the particular application of the science in which his own chief interest lies. Under the stimulating influence of a good teacher the student who may have originally intended to be a farmer finds himself more interested in perhaps medicine or metallurgy and his supplementary reading, study and ultimately his practice may be devoted to that application of the science of chemistry.

The agricultural student is most fortunate, however, when his work in chemistry is under the direction of some professor who came from the farm and whose interest in agriculture has grown with increasing knowledge of the laws of chemistry. With such instruction the student not only finds himself under competent guidance in the study of chemistry as such but also feels an increasing interest in and respect for the science as he sees the numerous points at which previously observed facts on the farm are clearly explained by the application of its principles.

Of necessity all men were not born to be farmers. Many students of chemistry have their chief interest in some other line of endeavor. It is probably best that the instructor in charge of the course in general chemistry in a high school, college or university be rather widely informed as to the applications of chemistry and sympathetic with the variety of needs of his students. It is too much to ask of him that he give to each group of students that more specialized instruction which is possible when they are classified in groups according to their intended profession and the instructor is chosen because of his special interest in that field.

In universities which include colleges of agriculture and in which the enrollment in that college is heavy, it should be possible to provide instruction in chemistry fitted to the needs of the student by choosing the instructor on the basis of his sympathetic interest in the application of the science to agriculture. Such a man need be no less of a chemist but he might well afford to be more of an agriculturist. Such an arrangement does not argue for a department of agricultural chemistry but it does make it essential to have a department of chemistry interested in agriculture. In the absence of such interest the department of agricultural chemistry has had its origin, has continued to exist and appears still to be essential in most state universities. For a similar reason the Smith-Hughes departments have been introduced into the high schools.

But soil science is more than chemical science. The soil is made up of particles of rock and its disintegration products, of living organisms and their remains and contains in its interstices varying amounts of water and air. The productivity of a soil is not determined entirely by its chemical content but also by its physical make-up and the activities of the biological agencies which find their home in it. The limiting soil factor in crop production may be a deficiency or an excess of water, oxygen or carbon dioxide as well as of the elements derived from the soil minerals. The extent to which the requirements of the crop can be satisfied is determined by the ability of the farmer to control the physical and biological factors quite as often as the chemical factors although they are all three intimately related. At any given time the primary cause of failure may not be known. If alfalfa fails to grow it may be because it is not inoculated, because the soil is too wet, because it is deficient in phosphorus or perhaps for the reason that the soil solution is too acid in reaction.

When soil is transferred to the laboratory it undergoes changes which alter its productive capacity. There is of necessity a field science of soils which has to do with the study of the soil as it exists and its classification as determined by the agencies which have had

to do with its formation, location and subsequent continued alteration. Fundamental to the study of this phase of soil science is the understanding of geological and climatological principles coupled with those of chemistry, physics and biology.

The man who presumes to teach the science of soils is, therefore, not a chemist or a biologist, a physicist or a geologist but he must know as much of the sciences represented by these specialists as has any significant bearing on his subject. In the absence of adequate training on his part or of his students in these sciences the teacher of soils struggles between teaching the art and the science of managing the soil. The art of agriculture is probably best taught on the farm. The real opportunity for agricultural teaching lies in the science of agriculture and in the capacity of the instructor to lead the student to see the application of science to his problem.

It is undoubtedly true that there is need that the art of agriculture be understood and that the student be trained in it. To milk a cow or to plow a furrow is not particularly difficult and yet one must know how. It is also true that the boy from the farm knows the art of agriculture largely only as it has been practiced on that particular farm. There is, therefore, the necessity for some one to gather together and present as a whole the various pieces of the agricultural art. That is what is supposed to be accomplished in the trade school where the student learns how to do the things which apply to his particular intended trade. The to-be farmer must learn how to lay a tile, to inoculate the alfalfa, to apply limestone or to calculate when he is getting his money's worth in fertilizer. These can be learned on the farms in almost every community although they may not be always gotten on any one farm.

Perhaps it is the function of the Smith-Hughes teacher in the high school or of the instructor in the agricultural college to teach the art of agriculture or of soil management to the end that the boy who takes the course may return to the farm prepared as he might have been in a trade school or perhaps somewhat more slowly even by continuing on the farm under the more or less competent supervision of his father. Or perhaps it is the privilege of the teacher of agricultural subjects to take advantage of the interest which the boy has in the art of agriculture to pave the way for a greater interest in the sciences which underlie the art.

In the study of soils in secondary schools it is essential to remember that the boy may already have in mind that he will later study in an agricultural college or that being stimulated by the interest aroused in the study of agriculture in the high school he may sub-

sequently so decide. In any event the study of soils leaves less time for a study of history, literature, mathematics, general science, language and other highly desirable subjects. If the student devotes his time at an early age to the study of the art or if the application of science rather than to the science itself, and in so doing neglects the other studies which are designed to enable him to interpret the past and anticipate the future progress of mankind he may be making a grave mistake. Similarly in college or university the student may decide to be a teacher or may become engaged in scientific research and may never return to the farm. No matter in what branch of agricultural work he may ultimately be engaged, he is best prepared for it when the instruction leads in the direction of understanding the basic principles with applications selected by the instructor from good practice in such a way as to insure the continued interest of the student.

Every "how" of soil management has a "why" back of it. Take for example the ordinary operation of plowing. When should a sandy soil be plowed? Why? What kind of a moldboard would be best on the plow to be used on a sandy soil? Why? If plowing a sandy soil with a steep moldboard when the soil is wet will improve its physical properties, there must be some general principle involved which would have some bearing on the plowing of any soil. What governs the working qualities of a soil?

Gradually the efficient instructor pushes the discussion in the direction in which there will be an unanswered why, first in the mind of the student, next in the mind of the instructor and finally in the mind of even the most advanced investigator. The student must somehow come to know that real progress in his education comes not from the knowing of isolated facts, but from a knowledge of principles which may have a great variety of applications in addition to those used as illustrations in the laboratory, field or classroom. The more fundamental these principles and the farther in the direction of the ultimate answers they reach, the more numerous will be their applications in practice to the man who understands them thoroughly.

The student of soils, particularly in the high school, but also in the university, must somehow be inoculated with the germ of dissatisfaction in the knowledge of practical facts alone which leads him on to desire to know what the study of physics, chemistry, geology and biology may have to offer in explanation of these facts. Admittedly, the successful farmer must practice farming and he may succeed financially without ever having seen the inside of a

book on science. He may manage the soil to the end that large yields of crops are produced without his having looked through a microscope or having worked with a chemical balance. If the high school or the college is to do anything more for his son than could be done for him in practicing agriculture on his father's farm, then it must get back of merely useful facts to the principles involved. What and why is the soil?

STUDIES ON THE EFFECT OF NITROGEN APPLIED TO OATS AT DIFFERENT PERIODS OF GROWTH.[1]

W. F. Gericke.[2]

Is the stage of growth of plants, or their age, when nutrients are applied a factor that affects the quantity and quality of product obtained from a given unit application of nutrient? To secure data on this subject was the purpose of series of experiments with a number of agronomic plants (cereals and noncereals) carried out in pot cultures under greenhouse conditions. Results from experiments with oats where nitrogen was supplied and made available to the plant at different periods of growth is the subject matter of this paper.

It was conceived to be probable, that if the different growth phases, or ages, of the plants when nitrogen is applied plays an important role in determining the magnitude of growth obtained from the treatment, that the differences would be greater if the tests were carried out with a soil that was deficient in nitrogen rather than one not lacking in this constituent. A very satisfactory soil was found in one known locally as Oakley sand. It was not only low in nitrogen, but had proved itself by many tests to be a soil that responded very quickly in increased crop production upon receiving even a moderate amount of either nitrate of soda or ammonium sulfate. The optimum water contents for plant growth in this soil was equal to approximately 18 percent of its dry weight. The containers used for the tests were glazed stone jars of cylindrical shape, of one-gallon capacity. The jars were filled to hold 5.5 kilograms of soil. The soil was seeded with a select strain of Texas Red oats. When the seedlings were about two inches high, they were thinned out to seven plants per jar.

[1] Contribution from the Department of Plant Nutrition, Agricultural Experiment Station, Berkeley, California. Received for publication, May 15, 1922.

[2] Assistant Professor of Soil Chemistry.

All of the essential features pertaining to the [illegible] investigation can be briefly stated as follows: The experiment was one in which the same kind of oats was planted at the same time, in the same kind of soil and subjected to the same climatic and cultural conditions. Each culture received the same kind of nutrient and the same amount of nutrient, but the nutrient was applied at different times in the growing period of the plants. That is, the plants were of different ages when they received nitrogen.

Two sets of tests were conducted, one using $NaNO_3$ and the other $(NH_4)_2SO_4$, as the source of nitrogen. All treatments were carried out in triplicate. The amount of nitrogen added per culture was at the rate of 82 pounds per acre on weight basis of 2,000,000 pounds of soil per acre. This was equal to 110 pounds per acre, calculated on basis of area. The application of nitrogen was 250 mg. per culture and was applied in solution at one time.

The data obtained from the investigation are given in tables 1 to 4, inclusive, of this paper:

TABLE 1.— *Effect of nitrogen applied to oats at different periods of growth on time of maturation of the plants.*

(Average of three cultures per set.)

No. of sets.	Date of planting.	Date nitrogen was applied.	Description of plants when nitrogen was applied.	Date of harvest. $NaNO_3$ series.	Date of harvest. $(NH_4)_2SO_4$ series.
1......	11/ 6/19	11/ 6/19	....	5/20/20	5/20/20
2......	11/ 6/19	11/25/19	10–15 cm. high, 3–4 leaves, color of flag normal.	5/20/20	5/20/20
3......	11/ 6/19	12/ 8/19	15–20 cm. high, 4–5 leaves, slightly pale as compared to set No. 1.	5/20/20	5/20/20
4......	11/ 6/19	12/23/19	25–35 cm. high, 5–6 leaves, noticeably paler than set No. 1.	5/28/20	5/20/20
5......	11/ 6/19	1/13/20	30–40 cm. high, 5–6 leaves, pale green as compared to No. 1.	5/28/20	5/28/20
6......	11/ 6/19	2/ 3/20	35–40 cm. high, 6–7 leaves, very pale green as compared to No. 1.	6/ 3/20	6/ 3/20
7......	11/ 6/19	3/2/20	40–60 cm. high, 6–7 leaves, pale green, tips of lower leaves dead.	6/10/20	6/10/20
Check..	11/ 6/19	....	....	6/10/20	6/10/20

Table 1 contains a brief description of the plants when nitrogen was applied and the dates when the plants were harvested.

The first application was not made to any growing plants, but to *the soil and the seed. Nineteen days after planting when the visible seedlings were approximately twelve days old, nitrogen as* $NaNO_3$ and as $(NH_4)_2SO_4$ was applied respectively to two sets of three cultures each. At this time it was not evident that any of the cultures were retarded in growth because of an insufficient supply of nitrogen. However, with all subsequent treatments, beginning with that made 33 days after planting, all untreated cultures were less vigorous and luxuriant than were those cultures which had already received nitrogen. The vigor and luxuriance of the untreated plants, as compared to those that had received nitrogen, became progressively less as they grew older.

It soon became evident that as a result of the treatments the different cultures in a series were at any given time (beginning six weeks after the experiments were started) in different phases of growth, although all were planted at the same time. The first plants to come to maturity were those of sets 1, 2 and 3 of the $NaNO_3$ treatment, and sets 1, 2, 3 and 4 of the $(NH_4)_2SO_4$, treatment. All subsequent applications of nitrogen to the cultures delayed maturity, when the plants are considered as a whole. But, if only the length of the growing period of the head-bearing stalks of the plants be considered, then the later the nitrogen was applied, the shorter was the growing period of the head-bearing stalks. This is explained by the fact that tillering started in all cultures after nitrogen was applied; and the later the tillers started, the shorter was their period of growth. The plants which matured last were those of the untreated cultures.

It appears from the results thus obtained, that under certain conditions when the rate at which nitrogen becomes available to oats is of such low order as not to permit of fairly good aerial growth of the plants, the life of a plant is thereby prolonged. Perhaps this is due to the slowing up of metabolic processes. This can arise from an insufficiency within the plant at certain times of the proper elements that are needed for the synthesis of plant products. While this condition may hold at times, under other conditions, as, for example, when the supply of nitrogen is deficient and air conditions make for excessive transpiration, the life of cereal plants may be shortened by the inadequate supply of a given nutrient.

Table 2 shows the effect of the treatments on the number of stalks produced and height of which they grew. As seven plants

TABLE 2.— *Effect of nitrogen applied to oats at different periods of growth on number of stalks produced and height of stalks.*

(Average of three cultures per set.)

No. of set.	Days after planting N was applied.	NaNO$_3$ series. No. of stalks.	Direction of maximum deviation from mean.	Height of stalks cm.	(NH$_4$)$_2$SO$_4$ series. No. of stalks.	Direction of maximum deviation from mean.	Height of stalks cm.
1.....	......	8.5	+1.5	165	12	± .0	158
2.....	19	11.3	+.7	164	13	±1.0	159
3.....	33	13.3	−1.3	166	15.7	−1.4	153
4.....	48	16.7	−.7	154	19.7	+2.3	153
5.....	69	16.7	−.7	149	20.3	+.7	148
6.....	90	22.0	±2.0	119	23.0	±.0	119
7.....	118	21.7	−1.7	97	22.3	+2.7	104
Check.	......	7.7	−.7	91	7.3	+.7	91

were allowed to grow in each jar, it is apparent that very little tillering occurred on the plants of the untreated cultures. The cultures that received $NaNO_3$ at the time of planting produced a small, but nevertheless, significant increase in number of stalks over those of untreated plants; and the cultures that received nitrogen as $(NH_4)_2SO_4$ produced decidedly more stalks than did the untreated cultures. All subsequent applications of nitrogen applied to different sets of progressingly older cultures up to and including those of set 6, resulted in a marked and apparently progressive increase of tillers. The exception to this continuity of progress is that of set 5 in the $NaNO_3$ series. Apparently the number of stalks in sets 6 and 7 is approximately of the same order of value and the maximum increase produced by varying the time in the growing period of oats when nitrogen was supplied was within that range delimited by these two sets.

The data further show that the application of nitrogen to these oat cultures at different periods of growth of the plants had a marked effect upon the height of the stalks. The tallest plants were produced in sets 1, 2 and 3 of the $NaNO_3$ series. The corresponding sets of the $(NH_4)_2SO_4$ series were shorter. Beginning with set 4 of the $NaNO_3$ series and set 5 of the $(NH_4)_2SO_4$ series, nitrogen applied to progressingly older plants produced correspondingly shorter stalks. The plants with shortest stalks were those of the untreated cultures.

If the height of stalks be multiplied by the number of stalks obtained for the different sets, an expression of response is obtained which is of a different order than that of either of the two factors. The progressive increase in number of stalks per culture produced by the treatment is eventually accompanied by a decrease in the height of stalks. That is, the direction for

the maximum attainment of either one of the two kinds of growth responses due to the same kind of treatment opposed the other. If a curve be plotted for total elongation of the cultures per set due to treatment it will be found to compare fairly well to that of [illegible] weight of the cultures of the serie[illegible]

The data showed that rather extensive tillering, induced relatively late in the growing period of oats, results in plants with short stalks. Two different factors may be conceived to account for the results: (1) the effect due to crowding and competition arising from excessive tillering may decrease height of stalks for number of stalks; or (2) since increasing number of tillers arose from applications of nitrogen made to increasingly older plants, and since the total length of the growing period of oat plants is probably determined by genetic factors, it may be that the later the tillers arise, the less time they have to grow and attain height.

TABLE 3.—*Effect of nitrogen applied to oats at different periods of growth on dry matter production.*

(Average of three cultures per set.)

No. of set.	Days after planting N was applied.	$NaNO_3$ series. Weight of grain gm.	Direction of maximum deviation from mean.	Weight of total dry matter gm.	Direction of maximum deviation from mean.	$(NH_4)_2SO_4$ series. Weight of grain gm.	Direction of maximum deviation from mean	Weight of total dry matter gm	Direction of maximum deviation from mean.
1.....	......	12.1	+2.7	43.7	+10.3	15.1	—.8	59.2	+3.6
2.....	19	14.3	+.4	64.1	—7.4	18.6	—1.8	66.5	+5.4
3.....	33	13.6	+1.4	75.3	+1.0	18.2	+1.7	67.6	+3.8
4.....	48	20.3	+.6	76.6	+9.4	21.6	—1.6	91.3	—12.0
5.....	69	20.6	+2.9	75.9	+4.5	20.1	—1.5	71.9	+12.3
6.....	90	25.7	—3.7	74.7	—7.7	22.2	+2.3	61.6	+6.4
7.....	118	13.2	+.2	35.9	+.7	15.9	—2.9	38.8	—6.2
Check.	......	2.6	.....	10.1	+1.7	2.6	+1.0	10.1	+1.7

Table 3 shows, first, that the production of grain and straw in the check or untreated cultures was very small as compared to that obtained from the cultures that received either $NaNO_3$ or $(NH_4)_2SO_4$; and second, that there was a decided increase in grain, straw and total dry weight in the cultures that received $NaNO_3$ and $(NH_4)_2SO_4$ at the time of planting. The production of grain, straw and total dry matter, however, was larger in the case of $(NH_4)_2SO_4$ than with that of $NaNO_3$. As the same amount of nitrogen was added in each case, it appears that these differences in yield must be due to differences in the physiological properties of the two salts. Also, there was, for the major portion of the period of treatment, correlated increase in yield

of grain, straw and total dry matter with each treatment applied to progressively older plants. That is, up to a certain age of the plants, the longer after planting before nitrogen was applied, the greater was the yield of straw and [illegible] maximum yield, however, did not [illegible] of applications for the dif[illegible] the maximum yield of grain came from set 6 where nitrogen was applied ninety [illegible], the maximum yield was obtained from set 3, that is, when nitrogen was applied forty-eight days after planting. As to the high point of total yield, the data are not definite for the $NaNO_3$ series. The yields of sets 3, 4, 5 and 6, are higher than those of the others, and are of approximately equal value. The maximum yield of grain from the $(NH_4)_2SO_4$ series, according to the data, was that of set 6, but in view of the value obtained from set 4, it appears that it would be better to state that the range of maximum values lies between set 4 and set 6. As to straw and total dry matter production, set 4 clearly gave the largest yields for the $(NH_4)_2SO_4$ treatments. Finally a decided decrease in yield of grain, straw and total dry matter from that of the maximum yield, resulted when nitrogen was applied as late as one hundred and eighteen days (set 7) after planting. In the case of $NaNO_3$, the yield of set 7 represents approximately a decrease of one-half of the maximum obtained when nitrogen was applied to cultures twenty-eight days before. The maximum yield of total dry matter for the treatment of $(NH_4)_2SO_4$ came with set 4, and this was followed by decreases in yield of total dry matter (due to a decrease in yield of straw) with each of the progressingly later applications of $(NH_4)_2SO_4$. The yield of grain of set 7 was approximately forty percent less than that of set 6.

TABLE 4.— *Effect of nitrogen applied to oats at different periods of growth on protein content of grain.*

(Average of three cultures per set.)

No. of set.	Days after planting N was applied.	Percent protein (air-dry basis): $NaNO_3$ series	Direction of maximum deviation from mean.	$(NH_4)_2SO_4$ series	Direction of maximum deviation from mean.
1	....	7.5	+.06	6.8	+.15
2	19	8.0	+.30	7.5	+.76
3	33	8.6	—.60	7.3	—.21
4	48	9.6	+.40	9.6	+.55
5	69	10.8	—.92	10.5	—.04
6	90	12.3	+.48	12.1	+.20
7	118	17.1	—1.30	13.9	+.60

Table 4 gives the percent of protein in the grain. It shows that the ages of the oat plants when nitrogen was applied markedly affected the protein content of the grain produced. The lowest percent of protein was obtained from the cultures that received nitrogen at the time of planting and the highest percent was obtained from the plants that received the latest treatment. The intervening treatments showed corresponding differences in percent of protein of the grain. That is, the older the plants were when nitrogen was applied, the higher the percentage of protein in the grain. The percent protein of the grain

TABLE 5.— *Comparison of data of table 4, ($NaNO_3$ series), with that obtained by calculation, using compound interest law of nine percent increase, compounded every fortnight.*

No. of set	Interval between applications of $NaNO_3$ (days)	Percent protein	Calculated interval (days)	Percent protein
1	....	7.5	....	7.5
2	19	8.0	*19	8.0
3	13	8.6	14	8.7
4	15	9.6	14	9.5
			14	10.4
5	21	10.8	....	....
			14	11.3
6	21	12.3	14	12.3
			14	13.3
7	28	17.1	14	14.5

* Includes germination period; 6–7 days required for seedlings to appear above ground, hence obtained value was used.

TABLE 6.— *Comparison of data of table 4 ($(NH_4)_2SO_4$ series) with that obtained by calculation using compound interest law of ten percent increase, compounded every fortnight.*

No. of set.	Interval between applications of $(NH_4)_2SO_4$ (days).	Percent protein.	Calculated interval (days).	Percent protein.
1	....	6.8	....	6.8
2	19	7.5	*19	7.5
3	13	7.3	14	8.3
4	15	9.6	14	9.1
			14	10.0
5	21	10.5	....	....
			14	11.0
6	21	12.1	14	12.1
			14	13.3
7	28	13.9	14	14.6

* Includes germination period; 6–7 days required for seedlings to appear above ground, hence obtained value was used.

of set 7 was 128 percent greater than that of set 1 in the $NaNO_3$ series, and 104 percent greater than that of $(NH_4)_2SO_4$ treatment for the corresponding sets.

The data of Tables 5 and 6 show that the increase in percent protein of the oats from the treatments follows fairly well the compound interest law of nine percent increase in protein content, compounded every fortnight for four months for the $NaNO_3$ series. For the $(NH_4)_2SO_4$ series, it is approximately 10 percent compounded every fourteen days. If, instead of compounding the increases obtained by the treatments every two weeks, it be compounded continuously, it is found that the data lend themselves to be expressed by the law of organic growth.

An inspection of Tables 2, 3 and 4 shows clearly that the variable factor employed in this investigation, namely, the differences in the ages of the oat plants when nitrogen was applied, produced correlated differences of growth responses. It appears, therefore, that the relative physiological status of oat plants expressed by differences in age and grown under the conditions described, is an important factor that affects the quantity and quality of product obtainable from a given unit application of nitrogen. Furthermore, it appears that this factor can be mathematically expressed and evaluated.

Reference has already been made to the differences obtained in results from equal applications of nitrogen, supplied as different salts, to oats. Analogous differences in yield of product from two different salts were also obtained in similar experiments with spring wheat, winter wheat, rye and barley. These marked and consistent differences in the magnitude of response obtained from equal applications of nitrogen, one supplied as $NaNO_3$, the other as $(NH_4)_2SO_4$, indicates that the cause must be due to differences in the physiological properties of the salts. One of these appears to be in the fact that some time is required for $(NH_4)_2SO_4$ to nitrify and become available as nitrate. An application of nitrogen as $(NH_4)_2SO_4$ should, therefore, according to the findings of these experiments, be expected to produce larger yields when applied at the time of planting than an equal amount of nitrogen applied as $NaNO_3$, because it becomes available as nitrate when the plants are of an age when this nutrient can be more efficiently used.

The results of the experiment appear to show that the age of the plants, grown under the condition described, is a very important factor in the measure of response that may be obtained from

a given unit application of nitrogen. Results obtained from similar kinds of experiments with other cereals confirm the above conclusions.

It appears desirable, however, to emphasize the fact that the results obtained from the differential treatments described are unusually large. Had a soil been used that was not so markedly deficient in nitrogen as the one used in these experiments, the results from so few tests would probably not have been so conclusive.

DISAPPEARANCE OF NITRATES FROM SOIL UNDER TIMOTHY.[1]

JAMES A. BIZZELL.[2]

An examination of the literature reveals an increasingly large amount of attention to the study of crops in their relation to the production of nitrates in soils. The bulk of this work seems to be concerned with the use of green manures and cover crops, and the relative rapidity with which plant materials or residues decompose in the soil with the formation of nitrates. Considerably less attention has been given to the production and disappearance of nitrates in the soil during the growth of the crop. Growing crops constantly remove nitrates from the soil and since plants of different species differ so much in their requirements for nitrogen the comparative effects of crops on nitrate production are somewhat difficult to determine. The accumulated data on this subject have now reached a fairly large volume and while the results are not always easy to interpret they contribute valuable information which is highly suggestive.

The difference between certain species of plants in their relation to the nitrate content of soil has been discussed at length in a previous publication of the Cornell Agricultural Experiment Station (1).[3] To summarize briefly — the nitrate content of soil under timothy, corn, potatoes oats, millet and soy beans was different for each crop when on the same soil. During the most active growing period of the corn crop nitrates were frequently higher under the corn than in cultivated soil bearing no crop. Under a mixture of corn and millet, the nitrates at this period

[1] Paper read at the meeting of the New Orleans meeting of the Society. Received for publication October 18, 1922.

[2] Professor of Soil Technology, Cornell University, Ithaca, New York.

[3] Reference by number is to " Literature cited " p. 326.

were higher than under millet alone although the total crop yields were about the same [illegible]. Under [illegible], the nitrate content was higher during the period when the crop was making its greatest draft on soil nitrogen than in later stages of growth in spite of the fact that the nitrates in the uncropped soil were increasing while those in the cropped soil were disappearing. Under these crops and under millet, nitrates failed to increase late in the season when nitrogen absorption had practically ceased although uncropped soil showed a very large increase in nitrates at that time. The authors suggested that the source of the great differences in the nitrates under the crops mentioned might be due to the inherent differences between plants of different species in their stimulating or inhibiting influence on the production of nitrates,— that during their later period of growth the plants exerted a depressing influence on nitrate formation. Timothy always maintained a lower nitrate content of the soil than did any other crop. A mixture of timothy, Kentucky blue grass and redtop gave similar results. These facts indicated a strongly repressive influence of these plants and suggested a possible cause for the injurious effect of grass sod in orchards on soil in which the supply of available nitrogen is deficient. Since the appearance of the publication cited, results have been obtained which show without exception that timothy and the grasses mentioned maintain a comparatively low nitrate content of the soil, in spite of the fact that grass crops require less nitrogen for growth than do any of the other crops studied. Further emphasis is given to this characteristic effect of grasses by results recorded in Memoir 12 of the Cornell Agricultural Experiment Station (2) to the effect that the drainage losses of nitrates from soil under grass have been smaller than from soil under any other crop. These facts have led us to make further inquiry into the relation of timothy to the soil nitrates, some of the results of which are reported in the present paper. Warrington (3) reported that the amount of nitrate nitrogen in the drainage water from the Broadbalk field, Rothamsted, was considerably less than was expected from the manure supplied and the crop reaped. He was of the opinion that the soil had lost nitrogen by denitrification and that the discrepancy was due to this cause. His result was not wholly experimental as it involved certain assumptions for which no direct evidence could be obtained. The results submitted in the present paper are likewise not entirely experimental, but the evi-

dence appears to be much more direct than that reported by Warrington, and since they point rather strikingly to certain modifications of the soil nitrogen it seems desirable to present them for discussion at the present time.

EXPERIMENTAL WORK.

The experiment was designed primarily to ascertain the effect of a nitrate fertilizer on the growth of apple trees in timothy sod. The soil used in this work is classified as Dunkirk clay loam, a rather heavy compact soil containing practically no material which does not pass the 2 mm. sieve. The nitrogen content in the surface foot is approximately 4,000 pounds per acre. Under favorable conditions of cultivation moisture and temperature, nitrification proceeds rather rapidly, but in its natural compact condition it does not seem to offer a very favorable medium. In the spring of 1917, one-year-old MacIntosh apple trees were set on 1/100-acre plots, using twenty trees per plot. All plots received annual applications of 450 pounds of acid phosphate and 240 pounds muriate of potash per acre. The first applications were made in the fall of 1917. Subsequent applications were made in the spring of each of the years 1919, 1920, 1921. Applications of nitrate of soda were made to certain of the plots in the spring of each of the years 1918, 1919, 1920, 1921. One set of four plots received no nitrate, while each of three other sets received respectively 100, 300 and 900 pounds per acre of nitrate of soda. The replicates of any particular treatment were distributed as much as possible to correct for lack of uniformity of the land. Timothy was seeded with rye in the fall of 1917 and the rye was mowed early in the spring of 1918. In the summer of each of the years 1918, 1919 and 1920 the timothy was cut and the hay left on the land. Determinations of nitrates were made each summer on the dates indicated in the accompanying tables. Samples of soil were taken by making nine borings on each plot to a depth of eight inches and a composite sample made from the portions so obtained. Nitrates were determined by the phenoldi-sulfonic acid method as described by Schreiner and Failyer (4). Moisture determinations were also made on these samples and the figures for nitrates calculated to the dry soil basis. The values for nitrates are expressed in terms of nitrogen pounds per acre-eight-inches using 2,500,000 pounds as representing the weight of the acre-eight-inches. The results are given in Tables 1, 2 and 3.

TABLE 1.— *Nitrate nitrogen, pounds per acre, applied and found during 1918.*

Plot numbers.	Nitrate nitrogen applied May 9.	Nitrate nitrogen found Sept. 4.
1001, 1008, 1104, 1112	None	3.39
1002, 1010, 1106, 1114	15.5	3.50
1004, 1012, 1101, 1108	46.5	2.99
1006, 1014, 1102, 1110	139.5	11.36

TABLE 2.— *Nitrate nitrogen, pounds per acre, applied and found during 1919.*

Plot numbers.	Nitrate nitrogen in soil April 21.	Nitrate nitrogen applied April 22.	Nitrate nitrogen found. July 8.	Aug. 15.	Oct. 11.
1001, 1008, 1104, 1112	2.63	None	2.98	6.19	3.37
1002, 1010, 1106, 1114	3.54	15.5	3.09	5.12	3.12
1004, 1012, 1101, 1108	3.79	46.5	3.39	5.20	3.16
1006, 1014, 1102, 1110	3.47	139.5	11.38	14.04	9.98

TABLE 3.— *Nitrate nitrogen, pounds per acre, applied and found during 1920.*

Plot—numbers.	Nitrate nitrogen in soil April 13.	Nitrate nitrogen applied April 26.	Nitrate nitrogen found. May 18.	June 11.	June 29.	July 15.	Oct. 28
1001, 1008, 1104, 1112	3.15	None	2.30	1.99	2.71	2.16	None
1002, 1010, 1106, 1114	4.52	15.5	3.12	1.99	3.39	2.40	Trace
1004, 1012, 1101, 1108	6.30	46.5	5.15	1.64	3.84	6.31	None
1006, 1014, 1102, 1110	4.77	139.5	47.90	25.40	16.98	11.65	5.27

The most striking effect shown by these figures is the rapid disappearance of the applied nitrate. Since the period during which this occurs coincides approximately with the period of most rapid growth of the timothy, it becomes of interest to know whether the assimilation of nitrogen by the crop is responsible for the removal of the nitrate. In order to obtain some evidence on this point, the apple trees were removed from the plots early in the spring of 1921. The fertilizers were applied to the timothy on April 25 after samples of soil were taken for the determination of nitrate nitrogen. On July 12 the timothy was cut, weighed and analyzed and samples of soil again taken for nitrate determination. The results are given in Table 4.

TABLE 4.— *Nitrogen, pounds per acre, applied and found during 1921.*

Plot numbers.	Nitrate nitrogen April 25. In soil.	Applied.	Total.	Nitrate nitrogen in soil and in crop July 12. In soil.	In crop.	Total.
1008, 1104, 1112	0.50	None	0.50	2.77	17.12	19.89
1010, 1106, 1114	1.24	15.5	16.74	2.37	20.90	23.27
1004, 1012, 1108	.68	46.5	47.18	3.33	34.59	37.92
1006, 1014, 1110	5.42	139.5	144.92	10.11	70.14	80.25

The figures for the disappearance of nitrates are similar to those obtained in previous years. From the results it appears that where no nitrate was applied nitrates were produced to the extent of 19.39 pounds per acre of nitrogen. The application of 15.5 pounds of nitrate nitrogen did not greatly increase the amount removed by the timothy. With the applications of 46.5 and 139.5 pounds nitrate nitrogen, there was an apparent loss of 9.26 and 64.67 pounds respectively. If it is assumed that the two heavier applications of nitrate have not interfered with nitrification, the discrepancy would be 29.15 and 84.56 pounds respectively. In this calculation, no account is taken of the possibility that the roots and stubble would also contain some of the absorbed nitrate. Since the timothy had been growing on this land for the three preceding years, during which time the roots had largely been produced from previously added nitrate, it does not seem likely that more than a very small proportion of the nitrate added on April 25 could have been contained in the roots of July 12. Granting however that the roots produced during the two and one-half months would be responsible for an amount equal to ⅓ the nitrogen contained in the crop we would still have an apparent disappearance, with the largest nitrate application, of 51.18 pounds nitrogen per acre.

NITRATES REMOVED BY LEACHING.

Unfortunately we have no direct means of estimating the loss of nitrates from these plots by leaching. We do have some indirect evidence on this point which seems to preclude the possibility of very much loss in this way. Grass has been grown continuously for nine years on certain lysimeter tanks, using the same type of soil as was used for the plots already described. The drainage from these tanks has been collected by yearly periods and the nitrates determined. The average annual removal of nitrate nitrogen in the drainage water from these tanks has been 1.45 lbs., while the largest removal in any year has been 6.8 lbs. per acre. We would hardly expect therefore to have an appreciable amount lost in this way from the plots, during the two and one-half months during which the timothy was growing. The losses from the lysimeters represent quantities passing through four feet of soil and there is the possibility that the applied nitrate was carried below the eight inch depth sufficient to account for the discrepancy indicated in Table 4. However, experience has shown that on this soil type nitrates do not

move downward with sufficient rapidity to make this explanation plausible. In field experiments it has been found that even where nitrates are produced in large quantities in the surface the lower strata have not been rapidly increased in concentration. An increase in the first foot of nitrate nitrogen from 37 pounds per acre in May to 170 pounds per acre in October was accompanied by an increase in the second foot of from 20 lbs. to 35 lbs. Further, the rainfall of the period April 25 to July 12, 1921, was exceedingly low, being only five inches, while the average during 1896–1916 for a similar period was eight inches.

LOSS OF NITROGEN FROM SOILS UNDER GRASS.

It is not known whether the apparent disappearance of nitrates in this experiment has been accompanied by a loss of nitrogen from the soil during the four years treatment with sodium nitrate. If it could be shown that the nitrogen content of the soil had been decreased at least part of the removal of nitrates could be attributed to denitrification with the evolution of elemental nitrogen. The nitrogen content of this soil before and after the growing of timothy has not been determined because it seemed very questionable whether the comparatively short duration of the experiment and the difficulty of obtaining satisfactory samples would permit of reliable information on this point. In another experiment on the same soil type in the same field, a mixture of Kentucky blue grass, redtop, and timothy has been grown continuously on the land for ten years. In no case has the nitrogen content of the soil decreased during the ten-year period. By sampling the plots in 1910 and again in 1920 it was found that as an average of eight plots the soil has gained in nitrogen to the extent of 250 pounds per acre foot, exclusive of that removed by the grass, which amounted to 347 pounds per acre; whereas an average of eight plots on which no crops were grown for ten years there has been a loss of 624 pounds of nitrogen per acre foot. In all cases where crops were grown in this experiment there was no loss of nitrogen from the soil that could not be accounted for in the crops removed.

DISCUSSION.

From the evidence presented it appears that the addition of sodium nitrate to timothy sod in the early spring is followed by a rapid disappearance of the nitrate from the surface eight inches of soil and that this disappearance is due only in part to the absorption of nitrogen by the growing crop. The evidence

presented indicates that the discrepancy is not due to leaching nor to the removal of nitr[illegible] by denitrification. It appears likely [illegible] ed for has been utilized by various organisms of the soil and that the nitrate is therefore transformed to ammonia or some organic combination. The accuracy of the balance sheet presented is, of course, subject to the limitations of the methods employed, particularly those used for determining nitrates and for the sampling of soils for nitrogen determination. However, the discrepancies observed are so greatly in excess of any probable inaccuracy of the methods the results seem to justify the formulation of the hypothesis already stated and a continuation of the study under more rigidly controlled conditions.

LITERATURE CITED.

1. Lyon, T. L. and Bizzell, J. A. Some relations of certain higher plants to the formation of nitrates in soils. Cornell Univ. Agr. Exp. Sta., Mem. 1. 1913.
2. ———— Lysimeter Experiments. Cornell Univ. Agr. Exp. Sta. Mem. 12. 1918.
3. Warington, R. Lost fertility: the production and loss of nitrates in the soil. Trans. Highland and Agr. Soc. Scot. Fifth series, 17: 148–181. 1905.
4. Schreiner, O. and Failyer, G. H. Colorimetic, turbidity and titration methods used in soil investigations. U. S. Dept. Agr. Bur. Soils Bul. 31. W906.

AGRONOMIC AFFAIRS.

NOTES AND NEWS.

E. N. Bressman, formerly assistant in Farm Crops at Iowa State College, is now head of the Farm Crops Department at the New Mexico State College.

C. S. Dorchester, formerly of the Farm Crops Department, Iowa State College, is now an instructor in Farm Crops at the Minnesota College.

R. R. Spafford, assistant agricultural economist, Bureau of Agricultural Economics, Department of Agriculture, has resigned to engage in business with his father at Falls City, Neb.

Plans were recently announced for the Yearbooks of the Department of Agriculture for 1922, 1923, and 1924. With the 1921 Yearbook, these are to complete a 4-year series of articles, each of which is intended to be a complete discussion of the history and economic status of the subject. The 1921 Yearbook contains articles on wheat, corn, cotton, and beef. The 1922 Yearbook will include hogs, dairying, hay, and forage, small grains,

and f[illegible]try. The subject[illegible] include fruits, potatoes [illegible] sheep, and goats. I[illegible] Yearbook there will be articles on horses and mules, roads and transportation, land utilization, land tenure, credit and [illegible], country life, and education. Each of the articles will include a large number of charts and graphic illustrations.

Asher Hobson of the Bureau of Agricultural Economics, Department of Agriculture, has been named delegate to the International Institute of Agriculture at Rome, succeeding Dr. W. H. Stevenson, who recently returned to Iowa State College.

C. V. Piper, in charge of forage crops investigations in the Department of Agriculture, was given the honorary degree of Doctor of Science by the Kansas State Agricultural College, in June.

Dr. G. R. Lyman, formerly in charge of the Plant Disease Survey of the U. S. Department of Agriculture, has been appointed Dean of the College of Agriculture of the University of West Virginia, at Morgantown, and will assume his new duties on January 1, 1923.

Dr. F. G. Cottrell was appointed, effective September 20, 1922, Director of the Fixed Nitrogen Research Laboratory of the Department of Agriculture, succeeding Dr. R. C. Tolman, who resigned to become Professor of Physical Chemistry in the California Institute of Technology.

Prof. L. A. Fitz, head of the Department of Milling Industry at the Kansas College, has been granted a year's leave of absence, and is now employed in the Research Laboratories of the Fleischmann Co., in New York City. During Professor Fitz's absence Associate Professor P. L. Mann will be acting head of the Department.

M. A. Carleton, formerly of the Office of Cereal Investigations of the United States Department of Agriculture, now in charge of the development of disease-resistant bananas for the United Fruit Co., has transferred from Panama to Honduras, where he will have better facilities for his work.

Prof. C. F. Marbut, of the Bureau of Soils, Dr. R. O. E. Baker, of the Bureau of Agricultural Economics, and Dr. H. L. Shantz, of the Bureau of Plant Industry of the U. S. Department of Agriculture, made a reconnaissance survey of the Southern Great Plains during the months of September and October. They studied the

distribution of the natural vegetation and of soil types, and also devoted attention to the agricultural economics of the region. The survey included portions of southwestern Nebraska, eastern Colorado, northeastern New Mexico, and the western portions of Kansas, Oklahoma and Texas, extending as far south as Corpus Christi, Texas. In all, about 5,000 miles were covered by automobile.

WESTERN CANADIAN SOCIETY OF AGRONOMY

The editor of this JOURNAL has received a copy of the printed Proceedings of the Second Annual Meeting of the Western Canadian Society of Agronomy, which was held at Winnepeg on December 27–29, 1921. It contains information with reference to the organization and membership of the Society and the following papers:

Address of President — T. J. Harrison.
Growing Grain in Rows — Manley Champlin.
Practical Crop Rotations for the Prairie Farmers — M. J. Tinline.
A Course to Train Specialists in Agronomy — D. W. Robertson.
Laboratory and Field Germination Tests — W. H. Wright.
Wheat-stem Rust from the Standpoint of Plant Breeding — H. K. Hayes and E. C. Stakman.
Discussion of Hayes and Stakman's Paper, "Wheat-stem Rust from the Standpoint of Plant Breeding"— J. B. Harrington.
Alfalfa Hybridization — W. Southworth.
A Comparison of Some Physical Properties of Immaturely Frosted and Non-Frosted Seeds of Wheat and Oats — Jas. R. Fryer.
Peat Land Farming — F. J. Alway.
Soil Colloids — C. B. Clevenger.
The Potato Scab Problem — G. B. Sanford.
Extension Methods that Get Results — S. T. Newton.

Copies of this report and the Proceedings of the First Annual Meeting of the Society are for safe at fifty cents each by the Secretary, Professor Roy Hansen, University of Saskatchewan, Saskatoon, Sask., Canada. A single copy of each of these Proceedings will be sent free, on request, to the library of each of the Agricultural Colleges in the United States.

JOURNAL
OF THE
American Society of Agronomy

VOL. 14 DECEMBER, 1922 No. 9

INCREASING THE EFFICIENCY OF AGRONOMIC RESEARCH.[1]

L. E. CALL.[2]

The field of agronomy is still a new one in America. Carleton[3] in his presidential address before the first session of this society in 1908 said, "In this country the segregation of agronomic work from general agriculture began with the new century. Before the year 1900 the word *agronomy* was rarely heard or written." The field of activity of the early agronomist was scarcely less restricted than that occupied by the earlier men in general agriculture. He had far too many duties and too many lines of activity to attempt the necessary specialization that would enable him to pursue any carefully planned line of research. A decade ago the agronomy department in most educational institutions was charged with the teaching and the investigational work in agricultural engineering and farm management, as well as in soils and crops, and its small staff attempted to do the extension work in these fields as well. It was not uncommon in our smaller institutions to find the same man engaged in all of these lines of activilty. In fact, fifteen years ago in some of the smaller departments the same man taught courses in general crops, soils, and farm machinery, and often did a limited amount of teaching in farm management and meteorology. In addition, some extension work, as well as experimental work, was attempted. Undoubtedly the greatest improvement in the efficiency of agronomic work in the past has come through gradual elimination of the diverse lines of activity of the agronomist. Today in most institutions the work of the department of agronomy is devoted

[1] Presidential address, presented at the annual meeting of the American Society of Agronomy, at Washington, D. C., November 20, 1922. Contribution No. 143 from the Department of Agronomy, Kansas Experiment Station.

[2] Professor of Agronomy, Kansas State Agricultural College, Manhattan, Kan.

[3] CARLETON, M. A. Development and proper status of agronomy. *In* Jour. Amer. Soc. Agron. 1:17–23. 1908.

exclusively to soils and crops, and in those departments which have the largest personnel, the men are devoting their entire time to teaching, research, or extension in one or the other of these fields. In fact, it is fully recognized that even greater specialization than this is not only desirable but absolutely necessary for the most efficient work. The entire field of either crops or soils is far too large for anyone engaged in research. The breeding of any one crop plant such as cotton, wheat, or corn will furnish a sufficiently large field for any investigator who is well trained in genetics. As the field of activity in crops and soils has been narrowed, the work in each field has improved. This has been the one outstanding contribution of the past twenty years toward greater efficiency in agronomic work.

INTERRUPTION CAUSED BY THE WAR.

The first lesson in efficiency, the need of specialization, had scarcely been learned and our institutions attained a state of development that would permit a reasonable degree of specialization when, due to the world war, all progress was interrupted The service of every available man was required for the conflict. Agronomists frequently proved to be the logical men to serve on committees to devise plans whereby the maximum production of food stuffs could be secured. All their time and thought were devoted to this work. Progress in the technical field of agronomy came to a standstill.

The reconstruction days following the war proved no more satisfactory. They brought problems that were even more distracting than those of the war itself. Prewar appropriations were no longer adequate to support teaching and research. The industries, because of the higher salaries they could pay, were taking the younger men of the profession. It was impossible to replace them. Students were not interested in graduate study. This was not surprising when at the completion of an undergraduate course they could enter a line of industry that would pay a larger salary than that commanded by some of the best trained men in the profession. Those days, however, are slowly but surely passing. Conditions are gradually adjusting themselves. Appropriations are more nearly adequate for the work. More students are interested in graduate study, and there is promise of a more abundant supply of well trained young men in agronomy in the future. However, the world war and reconstruction have occupied a period of time nearly one-half the length of the life of this society. When, therefore, we consider the progress that has been made in agronomic work during this time regardless of the many distractions, it should serve as a stimulus to us to push

forward with renewed energy now that the outlook is brighter for uninterrupted work.

LAYING PLANS FOR THE FUTURE.

Is this not a logical time to consider the defects and shortcomings of our work and to lay plans for more effective and efficient work in the future? The past, as I have endeavored to show, has taught the need of greater specialization. This lesson has been learned. There is some evidence that in certain cases specialization may have been carried too far, especially in the administration of agronomic work, but the principle of specialization has been firmly established.

If agronomic work is to reach the highest point of efficiency in the future, if we are going to improve upon the splendid service of the past, there are several fundamental considerations that must be recognized: (1) The importance of thorough basic training for research must be not only encouraged but insisted upon. (2) There must be a clear understanding of the importance of the research problems that present themselves and an effort must be made to confine our activities and energies to problems of greatest value. (3) There must be in those engaged in research such a love for the work as will enable them to push forward in the face of obstacles which may seem insurmountable. (4) There must be developed a spirit of consecration that will lead not only to a greater degree of cooperation among workers who are attacking the same problem but a closer cooperation among different state institutions, between state institutions and the federal government, between agronomists and workers in other allied sciences, and between agronomists and the general public as represented by industrial concerns and the farmer.

EXPERIENCE AND EDUCATION.

The proper training for the agronomist should start in early boyhood. This period preferably should be spent on the farm. A thorough knowledge of practical farm affairs and an understanding sympathy of the problems of farm life, best learned in the early boyhood days, are an essential foundation on which to build for technical work in agronomy. President Jardine,[4] in discussing this subject before this society in 1917, said: "A practical point of view is largely the result of boyhood training and an endowment of common sense. We who are now directing the training of future agronomists should make it our first article of faith to advise a boy to go into teaching or research in agronomy only when he has

[4] JARDINE, W. M. The agronomist of the future. *In* Jour. Amer. Soc. Agron. 9:385–390. 1917.

shown ample evidence of his thoroughgoing practicality." While a practical knowledge of agriculture is a necessary foundation for the best type of training in agronomy, it is only the first course in the foundation. Upon this must be placed a *general* four year college course in agriculture, followed by a thorough specialized training in those sciences related to the particular field of agronomy in which future work is to be done. It would be impossible to overemphasize the importance of thorough training in the fundamental sciences for the person who plans to engage in research in this field. This is absolutely necessary as the first step toward more efficient work. The war and the unsettled period following it interrupted the study of many who were doing graduate work and upset the plans of many others who were arranging for graduate study. This is a loss that will never be entirely repaired, and as a result, the efficiency of our work has suffered. It is encouraging, however, to observe an increasing interest in graduate study among the younger men in agronomy, as well as among students who have just completed their undergraduate work. It gives promise of a higher standard of work in the near future.

There is a danger that often accompanies thorough training in a specialized field. This is the failure to maintain a correct conception of the relative importance of other lines of work. The worker becomes so impressed with the importance of his own line of activity that the importance of the work of others is underestimated. This develops in time into a professional selfishness that warps the vision, stunts mental growth, and greatly reduces the efficiency of the worker. The danger of developing the so called " single track mind " can be avoided by taking time to investigate and to become interested in the work of others. The time spent for this purpose not only will broaden our vision and help us maintain a correct understanding of the importance of our own work but may give us new ideas that will open up new lines of attack on our own problems. We have represented in the American Society of Agronomy as it is now constituted a sufficient number of lines of research activity to enable those of us who attend the meetings to maintain a fairly broad vision of closely related fields of work. This helps us maintain a breadth of vision that we all need. The man who is devoting his time to field crop genetics is benefited by the discussion of some phase of soil biological work, and in the same way the man engaged in research in soil biology profits by the discussion of the problems of the plant breeder. We may derive even greater benefit in this connection by attending meetings of other societies of pure and applied science. Every

possible opportunity should be used for this purpose: This would eliminate much of the danger of too great specialization, provided through such gatherings as these, and in other ways, a broad vision is secured and a sympathy maintained for other lines of work.

RESEARCH AND OTHER DEMANDS.

In the past the efficiency of agronomic research has been retarded not only by inadequate training and by a constant pressure from the general public for special services, but by poor organization and a failure to grasp the importance of the various problems and to attack those only of the greatest economic importance. While the lack of training on the part of those engaged in agronomic research is being rapidly overcome and while the demand for public service is less urgent than during the war, there nevertheless is a constant demand upon most of us in federal and state institutions for such service We constitute a part of public institutions whose only justification for existence is to serve the people, from whom we obtain our support. Good service leads to an ever increasing demand for additional help. Some of our colleges are developing as service institutions to the point where public demand is so strong that a majority of the time of the entire force of the institution is utilized in this way. It should be remembered that the best service is not necessarily performed when only the call of the hour is answered. Frequently the man in the laboratory working on fundamental problems proves in the end the better public servant. Both types of service must be performed and the most efficient institution is the one which retains the proper balance between these two lines of work. It is often possible to combine basic research with the solution of some practical problems of timely interest. The farmer may be interested in the best crop variety to grow. It is the agronomist's duty to give him this information. While this information is being obtained it may also be possible, if the work is properly planned, to study some of the factors that influence the productivity of the crop under investigation. Thus research of a fundamental nature may often be combined with the more routine types of work that we all must pursue.

Are we wasting time on work that is poorly organized? Are we attacking the problems that are of the greatest importance? Are we marking time because of being engaged in lines of research that we are unable to pursue properly with the resources at our command? If so, are there not problems of the greatest importance that might be attacked with the resources at hand with reasonable assurance of bringing the work to a successful conclusion? Is

there not also a possibility that research methods are being used that are expensive, that consume time excessively, that might be replaced by simpler and less expensive methods? Greater efficiency in research work in agronomy can be brought about by better adaptation of research methods to the problems under investigation, by a more careful organization of the work, and by a thorough study of the problems under investigation; eliminating those upon which progress is not being made and placing greater exertion and energy on those that remain which are of greatest value.

ESPRIT DE CORPS.

There has never been the esprit de corps in agronomy that exists in some of the older branches of science. Until we develop such love for our profession that we are willing to make sacrifices in salary and mere official rank in order to stick to agronomic research, we cannot hope that proper progress will be made by the profession. The American Society of Agronomy in the short period of its existence has had a total of fourteen presidents. Of this number only four remain today in purely agronomic work. Two have become college presidents, four are experiment station or extension directors, two have retired from active service, and two are engaged in commercial fields of work. Perhaps the loss of these men from the field of agronomic research would not have been so serious, because most of them while agronomists were already engaged chiefly in administrative work, had it not been for the fact that when they resigned, their places for the most part were taken by men engaged in research who had won recognition because of their achievements in this field. As long as it remains the practice to take the best research men in agronomy for administrative work it will be impossible to make research work as efficient as it should be. It is regretable that in many institutions it is impossible financially to reward efficiency in research as liberally as efficiency in administration and extension. The United States Department of Agriculture is to be congratulated that Congress has made possible a salary scale for a few men engaged in research higher even than that of the bureau chiefs themselves. These positions should be filled as rapidly as suitable men can be obtained to fill them. They will be filled at the maximum salary available for the position if the administrative officers of the department are willing to lay aside personal feeling in the interest of the development of research. It is recognition of this kind that will hold our best men in research. It is recognition of this kind that will develop an esprit de corps within the ranks of agronomy. May we not hope that the action of Con-

gress in recognizing the value of research marks the beginning of a new day for the men engaged in investigational work?

COOPERATION.

Although thorough training, well developed plans, and love for the work are essential for efficient research in agronomy, they are perhaps less important than a spirit of cooperation in the workers. We have passed the pioneer days in agronomic research when it was possible for an individual working alone to make rapid progress. The problems before us are complicated, they require for solution the best judgment of a number who are specialists in different lines of work and who can view the problems from different angles. The most hopeful sign of increasing efficiency in agronomic work is the growing spirit of cooperation among those working together in agronomy and between agronomists and those engaged in other fields of science.

Cooperation Among Agronomists.

In several sections of the United States where climatic and soil conditions are similar we have agronomists working on problems that are similar, if not identical. While some duplication of work is usually desirable, is there not wasted effort in much of the duplication that exists in agronomic work to day?

We are able to learn something of each other's work in meetings of this kind and in the sectional meetings of the society. We also learn much from published papers and occasional visits to other institutions, but this does not afford the type of cooperation that we should have or that we must have if the work is to be most effective. It should be possible for those engaged in the same line of research in adjoining states of similar character to meet together in smaller groups at least once a year to discuss their work and to advise with each other as to the best way of attacking their problems. Work that is being contemplated should be presented at such meetings and an endeavor made to secure the necessary cooperation on the problem without the danger of unnecessary duplication. The amount of money required to travel to meetings of this character would be insignificant as compared with money which could be saved. The results accomplished by such meetings cannot be measured, however, in money. The most important result is the stimulation to the worker that would come from such gatherings. The soil fertility schools that have been held by the Soil Improvement Committee of the National Fertilizer Association and the conference on lime held in September at the University of Tennessee are steps in this direction. Such conferences are having a tremendously

stimulating influence on the work in these fields. What we should have are more conferences of this character, but before this is possible, our administrative officers must recognize the value of such meetings and arrange for the traveling expenses of the delegates. This, I believe, will come when we who are engaged in the work demonstrate our belief in the value of such meetings by attending some of them at personal expense.

Cooperation Between Agronomists and Other Scientists.

The agronomist must have a thorough training in closely related sciences, not with the expectation of becoming a specialist in these fields of study — for that would be impossible — but for the purpose of recognizing, in any problem that he may undertake, the relation of the various sciences to it. When he recognizes that some other science may contribute to its solution, he should be broad-minded enough to invite cooperation. For example, if the plant pathologist and the agronomist work independently of each other, progress will be slow in developing disease resistant strains of crop plants. Likewise, the agronomist and the entomologist working in cooperation will make much more rapid progress in devising methods of insect control than by working alone. In the same way the agronomist must cooperate with the geologist, the physicist, the bacteriologist, and the chemist in the solution of difficult soil problems. It is in this way that the problems of the future will be solved. The agronomist cannot hope to be a plant pathologist, a plant physiologist, an entomologist, or an ecologist, a physicist, a chemist, or a bacteriologist. He can, however, have the helpful cooperation of these other scientists in many of our well organized institutions if he has the character and the vision to invite their cooperation and to avoid anxiety about who is to get credit for the work. One of our greatest needs today is a group of workers who are willing to forget self for the sake of service.

Cooperation Between the States and the Federal Government.

There has been a splendid spirit of cooperation in the past between the Bureau of Soils and the Bureau of Plant Industry of the United States Department of Agriculture and the Departments of Agronomy of most of the land grant institutions. This has led to extensive and highly satisfactory cooperative work that has been of the greatest help to the land grant institutions, and I believe satisfactory as well to the United States Department of Agriculture. Most agronomic problems are not bounded by state lines. Many of them are regional or even nation-wide in their application. The broader viewpoint which the United States Department of Agriculture must

necessarily take is of the greatest value to the local worker, while on the other hand, the close personal touch which only the man on the job can have has no doubt been of similar value to workers in the Federal Department. How long would it have taken us working alone in state institutions without the cooperation of the Office of Cereal Investigations of the Buréau of Plant Industry to learn that there are regional strains of black stem rust (*Puccinia graminis tritici*)? How long would it take to determine the winter hardiness of a new strain of wheat if it were not for the winter hardiness nurseries of the United States Department of Agriculture conducted in cooperation with the states extending north and south across the country? What progress would the individual states have made in classifying the soils of this country if it had not been for the cooperation of the Bureau of Soils with the various states in soil survey work? These are but a few of many examples that might be cited of the value of the cooperation that has existed in the past between the states and the federal department in agronomic work. Greater efficiency in agronomic work in the future will come through closer cooperation between these agencies than has existed in the past. This will take place if we all endeavor to *give* as much as possible rather than to *get* as much as possible from our cooperative work.

Cooperation Between the Agronomist and the Public.

Of necessity is the agronomist in close contact with the farm and the public. In common with other agricultural workers he is more or less of a middle-man between the man of so called pure science and the man on the farm. It is to the agronomist that the farmer should naturally come with a crop or soil problem. If the agronomist is practical enough and scientific enough to apply the principles of science to the problems of the farm, he will secure the confidence of the farmers and bring about a cooperative relation that will be mutually beneficial. The farmer will obtain the service that he desires, while the agronomist will at all times be informed as to the problems of the farm that require attention.

There is developing rapidly a more friendly relation between the agronomist and agricultural industrial concerns. The industrial concerns are learning that the agronomist is not altogether a theorist, and the agronomist is learning that many industrial concerns dealing with the farmer are endeavoring to render a real service to agriculture. This has led to most friendly cooperative relations with a number of agricultural industries, as, for example, the National Fertilizer Association through its Soil Improvement Committee, the

National Lime Association, and more recently firms interested in the sale of sulfur for agricultural purposes. When we consider the possibilities in this field we are impressed with the small beginning that has been made and the number of lines of industry with which we, as agronomists, should be cooperating.

SUMMARY.

If agronomy in the future is to make the rapid progress that has been made in the past, if it is to retain its present standing in the rapidly developing field of agriculture, if it is to accept its opportunity to render to society the service that the future will afford, a greater effort must be exerted among agronomists to secure the proper, fundamental training for their work. There must be developed an esprit de corps that has not existed in the past. Greater efficiency in research must be secured by closer cooperation and a more generous attitude: first, among agronomists in different state institutions; second, between agronomists in state and in federal work; third, between agronomists and other scientists; fourth, between agronomists and those engaged in industrial enterprises; and, fifth, between agronomists and the general public. These are the conditions necessary for effective work. Is there any reason to doubt that they will be fully accepted? I think not, for there has never been a time when the need for thorough training was more fully appreciated, when workers in agronomy were more earnest, when the desire for cooperation was more sincere, or when the opportunities for service were greater. Nothing must prevent the agronomists of the future from accepting these opportunities.

REDUCTION OF NITRATES CAUSED BY SEED AS A POSSIBLE FACTOR IN THE ECONOMY OF NITROGEN IN CROP PRODUCTION.[1]

JEHIEL DAVIDSON[2]

INTRODUCTION.

As early as 1868, Schönbein (1)[3] reported the fact that water extracts, prepared from seeds of higher plants, possess the faculty of reducing nitrates to nitrites and other more advanced products of reduction. He thought that the dissolved organic materials present

[1] Contribution from the Laboratory of Crop Chemistry, Bureau of Chemistry, U. S. Dept. of Agriculture. Presented at the 12th annual meeting of the American Society of Agronomy, Chicago, Ill., Nov. 10, 1919. Received for publication October 2, 1922.

[2] Soil Chemist.

[3] Reference by number is to "Literature cited," p. 354.

in the extracts had certain catalytic properties similar to those of platinum black and that the reduction was a phenomenon connected with the chemical activation of oxygen as in the case of ozone. In the light of the later theory of enzymes, Schönbein's explanations might be interpreted to mean that the reduction of nitrates by seed extracts was caused by reducing enzymes.

It is now generally accepted, however, that the denitrification attributed directly to the seed by Schönbein is caused by reducing microorganisms which use the materials contained in the seed as food. For instance, toluene, which inhibits bacterial activity but does not affect enzymic action, completely prevents the formation of nitrites by seed in a nitrate solution. Seed which was heated at a temperature of 100° C. for about 24 hours, for the purpose of destroying its vitality, did not lose its ability to reduce nitrates, as will be shown in this paper. The prolonged heating at 100° C. would seem to be sufficient to destroy all the enzymes in the seed. The organisms concerned in the reduction of nitrates indirectly caused by seed, whether found only where grain is grown and stored or not, seem to be of common occurrence. Seed belonging to different varieties, obtained from different harvests and different localities, gave results showing the same denitrifying tendencies.

The object of the work here reported was to obtain quantitative measurements which would give an idea of the possible extent of the reduction of nitrates caused by seed. It was thought that such data would indicate the limits of speculation as to what might happen under actual field conditions.

EXPERIMENTAL WORK.

It was not considered necessary to conduct the experiments under controlled conditions of culture and temperature. The nature of the organisms involved was beyond the scope of this work, which was intended to demonstrate collective results under natural fluctuating conditions. The mixed unidentified causal organisms either were associated with the seed or occurred in laboratory air. The temperature in the laboratory where the experiments were conducted varied with the fluctuations in temperature outside, especially with the changes in the day and night temperature, and with seasonal fluctuation as the work covered a period of several years. This accounts for certain quantitative variations which will be observed in the tables. The figures in these tables should be considered as representing relative rather than absolute values, inasmuch as they were obtained under certain imposed conditions. The tendencies which they reveal, however, are clearly defined.

INFLUENCE OF BASIC RADICLES ON THE REDUCTION OF NITRATES INDUCED BY SEED.

Of the nitrates selected to test the influence of the basic radicles on the process of reduction some are common in soils either naturally or as fertilizers, as the nitrates of sodium, potassium, calcium, magnesium, and ammonium, and some are found only rarely, or in minute quantities, as the nitrates of manganese, barium, cobalt, and copper. The solution of sodium nitrate used had a concentration of 1000 parts per million. The other nitrates were used in normal proportions, so that the concentration of the nitrate radicle was the same in all the solutions.

Two grams of wheat seed was placed in 250 cc. beakers containing 200 cc. of the solution to be tested. The beakers were covered with watch glasses and allowed to stand in the laboratory. At certain intervals aliquots (usually 5 cc.) of the solutions were pipetted off for nitrite determinations which were made colorimetrically, using the modified Griess reagent and a Schreiner colorimeter. The results are reported in parts per million of NO_2. The same procedure was followed in all experiments. The rate of reduction is judged by the accumulation of nitrites in the solutions from day to day and by their gradual disappearance. The ultimate test, however, is the disappearance of the nitrites which in the great majority of cases coincides with the total disappearance of the nitrates.

The first experiment was begun November 18 and concluded December 13. The results are given in Table I.

The process of reduction was sluggish as compared with that of some of the later experiments. A certain intermittence in the accumulation of nitrites indicates that the reduction of the nitrates to nitrites and to the further stages was going on simultaneously. The sluggishness of reduction may have been due to the season of the year. The time when this experiment was conducted corresponds to the period of the year when, according to Moore (2) the reduction of nitrates to nitrites by sunlight is the lowest. While the reduction of nitrates in these experiments is certainly microbiological, and while the nitrite accumulations induced directly by sunlight generally fluctuate between fractions of one part per million and, therefore, could not appreciably affect the quantitative determinations reported here, sunshine intensity may be an important factor affecting the activities of the organisms involved in the reduction of nitrates.

The disappearance of the nitrites occurred earlier in the calcium and magnesium nitrate solutions than in the others. This, however, may have been accidental. The behavior of manganese, which is

TABLE 1.—*Influence of basic radicles on the reduction of nitrates induced by seed.*

(Parts per million of NO_3)

Nitrates.	After 1 day.	After 3 days.	After 4 days.	After 5 days.	After 7 days.	After 8 days.	After 10 days.	After 11 days.	After 12 days.	After 14 days.	After 15 days.	After 17 days.	After 18 days.	After 19 days.	After 20 days.	After 22 days.	After 25 days.
Sodium nitrate....	.5	12	25	16	63	48	160	120	80	60	120	30	Trace	Trace	....	....	....
Sodium nitrate....	.4	20	40	50	54	80	160	120	50	1	1	Trace	Trace	Trace	....	....	....
Potassium nitrate..	.4	12	35	30	72	80	180	140	120	100	120	60	12	None	None	....	....
Potassium nitrate..	.5	7	20	16	45	32	100	60	....	30	30	30	30	8	None	....	....
Calcium nitrate...	.2	14	30	20	72	48	120	120	80	40	Trace	Trace	None	....	....	....	....
Calcium nitrate...	.3	8	20	25	90	80	160	120	100	.4	Trace	Trace	None	....	....	....	....
Magnesium nitrate.	.3	20	40	35	144	80	160	5	Trace	Trace	None	....	None	....	....	....	....
Magnesium nitrate.	.4	17	40	35	90	80	160	100	80	80	Trace	Trace	None	....	....	....	....
Ammonium nitrate.	.7	22	50	25	72	60	160	....	120	120	100	80	24	None	Trace	....	....
Ammonium nitrate.	2.4	14	40	50	126	60	140	120	80	120	120	80	80	24	40	Trace	Trace
Manganese nitrate.	.3	4	14	20	63	60	120	100	50	100	100	60	50	24	32	Trace	Trace
Manganese nitrate.	.3	1.2	3	5	22	24	100	80	50	100	80	80	80	40	50	24	Trace
Barium nitrate....	.1	8	24	40	108	50	140	120	60	120	50	40	None	....	....	....	....
Barium nitrate....	.1	12	45	30	63	100	140	100	100	1	.6	Trace	None	....	....	....	....
Cobalt nitrate.....	Trace	Trace	Trace	Trace	Trace	Trace	Trace	....	....	....	....	....	....	....	....	....	....
Cobalt nitrate.....	Trace	Trace	Trace	Trace	Trace	Trace	Trace	....	....	....	....	....	....	....	....	....	....
Copper nitrate....	None	None	None	None	None	None	....	....	....	....	....	....	....	....	....	....	....
Copper nitrate....	None	None	None	None	None	None	....	....	....	....	....	....	....	....	....	....	....

known to be toxic to higher plants in relatively high concentrations (3) *is of interest. While in the* concentration used in this experiment, which is to be consdered as high, manganese would seem to have retarded slightly the accumulation of nitrite in the beginning and its disappearance at the end, it nevertheless left the process of reduction essentially unchanged. Cobalt and copper, in the concentrations used in this experiment, entirely prevented reduction.

The results show that the basic radicles of the common nitrates do not affect essentially the process of nitrate-reduction induced by seed. In the subsequent experiments sodium nitrate, the most common nitrate in fertilizers, was used.

Influence of the Quantity of Seed on the Reduction of Nitrates.

Definite weights of wheat seed were placed in 250 cc. beakers, and 200 cc. of a 1000 p.p.m. sodium nitrate solution was measured into each beaker. The beakers were covered with watch glasses and allowed to stand in the laboratory as in the previous case.

This experiment was begun January 23 and concluded February 12. The results are given in Table 2.

The influence of the larger quantities of seed was to hasten the process of reduction, especially in the more advanced stages which are marked by the disappearance of the nitrites. The maximum nitrite concentration of 600 parts per million was obtained with one gram of seed. It is possible that the rapid disappearance of nitrites began at a lower concentration in the case of the larger quantities of seed. It is also possible, however, that the maximum readings in the case of the larger quantities of seed indicate the first steps in the further reduction of the nitrites. The highest concentrations might have occurred between the date of the apparent maximum and that of the first reading which registered the more advanced reductions as indicated by the decrease in nitrite occurrence. It should be noted that in the case of the highest quantity of seed the total accumulation of nitrites disappeared in a period of time not exceeding two days.

Influence of the Concentration of the Solution on the Reduction of Nitrates Induced by Seed.

Two grams of wheat seed was weighed into each beaker and 200 cc. of each solution was measured into the beakers. The concentration of the solutions ranged from 100 to 10000 parts per million. The experiment was begun March 28 and terminated April 20. At that date the nitrites had not disappeared in the highest concentrations. The results are given in Table 3.

TABLE 2.—*Influence of the quantity of seed on the reduction of nitrates.*

(Parts per million of NO_3.)

Quantity of seed, gms.	After 1 day.	After 2 days.	After 3 days.	After 4 days.	After 6 days.	After 8 days.	After 9 days.	After 10 days.	After 11 days.	After 13 days.	After 14 days.	After 15 days.	After 16 days.	After 17 days.	After 20 days.
1	.....	3.2	13.0	20.0	47.5	93.7	250	400	450	600	550	520	450	320	Trace
1	.....	3.2	10.0	17.5	42.5	81.2	225	320	400	550	450	440	280	None	None
2	.....	8.5	37.5	45.0	106.2	400.0	360	.....	450	143	None	None	.....	.....	.....
2	.....	7.0	37.5	55.0	110.5	320.0	400	.....	312	None	None	.....	.....	.....	.....
5	5.0	37.5	137.5	200.0	237.5	440.0	16.5	.....	None	None	.....	.....	.....	.....	.....
5	4.5	50.0	150.0	275.0	300.0	440.0	None	.....	None	.....	.....	.....	.....	.....	.....
10	10.0	50.0	200.0	275.0	520.0	140.0	None	.....	None	.....	.....	.....	.....	.....	.....
10	10.0	57.5	175.0	275.0	480.0	200.0	None	.....	None	.....	.....	.....	.....	.....	.....
20	15.0	60.0	187.5	312.0	400.0	None	None	.....	None	.....	.....	.....	.....	.....	.....
20	13.0	80.0	225.0	375.0	440.0	None	None	.....	None	.....	.....	.....	.....	.....	.....

TABLE 3.—*Influence of the concentration of the solution on the reduction of nitrates induced by seed.*

(Parts per million of NO_3.)

Concentration $NaNO_3$, p.p.m.	After 2 days.	After 3 days.	After 5 days.	After 7 days.	After 8 days.	After 10 days.	After 12 days.	After 14 days.	After 16 days.	After 17 days.	After 19 days.	After 23 days.
10,000	30	70	100	160	280	112	175	480	560	440	560	560
10,000	35	70	80	140	320	110	200	520	640	440	560	640
5,000	25	70	100	140	400	100	440	520	640	720	900	800
5,000	60	90	120	320	560	175	440	550	720	720	480	80
2,000	30	80	120	400	640	150	18	16	64	None	10.0	None
2,000	30	70	120	320	400	140	Trace	......	......	......	......	......
1,000	30	70	120	100	12.0	90	None	......	......	......	......	......
1,000	50	80	137	5.0	6.0	90	None	......	......	......	......	......
500	25	80	110	1.5	2.5	7.0	None	......	......	......	......	......
500	30	80	120	1.5	2.5	50	None	......	......	......	......	......
200	12.5	60	5.0	2.0	2.5	3.0	None	......	......	......	......	......
200	25	80	3.0	2.0	2.5	3.0	None	......	......	......	......	......
100	25	40	2.5	2.5	2.0	4.0	None	......	......	......	......	......
100	30	40	2.0	2.5	2.0	4.0	None	......	......	......	......	......

Beginning with the concentration of 2000 parts per million, the experiment ran its normal course, except for a certain fluctuation in the accumulation of nitrites. Attention is directed to the large accumulation of nitrites obtained in the higher concentrations of sodium nitrate.

The lowest concentration of 100 parts per million of sodium nitrate used in this experiment is frequently found in soils under natural conditions. The reduction in this concentration followed the same general tendency. Higher concentrations of 1000 parts per million were used in the subsequent experiments for the purpose of better demonstration.

INFLUENCE OF SURFACE STERILIZATION OF THE SEED ON THE REDUCTION OF NITRATES.

The experiment was conducted in 250 cc. beakers with 200 cc. of solution having a concentration of 1000 parts per million. Two sets of beakers, one with sterilized seed and one with untreated seed, were used. The seed was sterilized by soaking it in a solution of mercuric chloride (1 : 1000) for 20 minutes. The experiment was begun February 22 and terminated April 4. The results are given in Table 4.

The surface sterilization of the seed retarded the beginning of the process of reduction for about four days. The organisms which were at work in the sterilized set of beakers were either those reinoculated from the air of the laboratory or those of the original flora associated with the seed which survived because of imperfect sterilization. The retardation was probably caused either by the length of time required for inoculation in the case of the first alternative or by that required for the residual organisms to multiply in the case of the second alternative. The disappearance of the nitrites was not as rapid in the case of the sterilized seed as in the case of the untreated seed, probably because of the change produced by the sterilization of the seed in the composition of the causal flora.

INFLUENCE OF THE DEPTH OF THE LIQUID ON THE REDUCTION OF NITRATES INDUCED BY SEED.

All the experiments so far reported were conducted in 250 cc. beakers, using 200 cc. of solution. Under these conditions the depth of the liquid was about 6.5 cm. It has been assumed that the process of reduction in these experiments was anaerobic in character, as in the case with biological reduction in general. It seemed desirable, therefore, to determine whether the depth of the liquid had any distinct effect on the process, especially in view of the fact that the depth of standing water over agricultural fields seldom reaches 6.5 cm.

TABLE 4.—*Influence of surface sterilization of the seed on the reduction of nitrates.*

(Parts per million of NO_2.)

Quantity of seed, gms.	Treatment.	After 1 day.	After 2 days.	After 4 days.	After 6 days.	After 7 days.	After 8 days.	After 9 days.	After 12 days.	After 15 days.	After 19 days.	After 23 days.	After 25 days.	After 26 days.	After 30 days.	After 33 days.	After 37 days.	After 40 days.	After 41 days.
10.......	Sterilized	None	Trace	0.3	12.5	62.5	120	160	240	140	120	80	40	40.6	31.2	32.0	4.5	5.0	Trace
10.......	Sterilized	Trace	Trace	0.3	10.0	68.7	180	225	400	240	160	240	100	112.5	90.0	90.0	100	5.0	Trace
5.......	Sterilized	Trace	Trace	0.2	37.5	75.0	200	360	280	326	Trace	8	Trace	None	.....	.....	.....	.....	.....
5.......	Sterilized	Trace	.03	0.4	62.5	75.0	260	225	250	225	120	175	Trace	None	.....	.....	.....	.....	.....
2.......	Sterilized	None	None	0.3	64.0	75.0	220	250	140	6	Trace	Trace	Trace	22.5	None	None	.....	.....	.....
2.......	Sterilized	0.3	0.4	10.0	125	87.5	250	250	300	100	Trace	Trace	Trace	22.5	None	None	.....	.....	.....
10.......	Not sterilized	25	50	150	250	12.0	None	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10.......	Not sterilized	37.5	75	150	.....	0.1	None	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.......	Not sterilized	25.0	62.5	137.5	275	37.5	None	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5.......	Not sterilized	25.0	81.2	150	160	1.2	None	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.......	Not sterilized	15.0	45.0	100	260	240	350	300	None	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2.......	Not sterilized	22.5	60.0	110	300	300	32.5	200	Trace	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Two grams of wheat seed and 200 cc. of a 1000 p.p.m. sodium nitrate solution were used in each case. Vessels of different diameters were used in order to obtain the different depths of liquid. The experiment was begun March 28 and concluded April 9. The results are given in Table 5.

TABLE 5.—*Influence of the depth of the liquid on the reduction of nitrates induced by seed.*

(Parts per million of NO_3.)

Depth of liquid, cm.	After 2 days.	After 3 days.	After 5 days.	After 7 days.	After 8 days.	After 10 days.	After 12 days.
1.5	25	70	80	156	180	125	None
1.5	12	60	90	140	160	160	None
6.5	30	70	120	100	12	90	None
6.5	50	80	137	5	6	90	None
22.0	50	90	180	2.5	3	50	None
22.0	40	90	140	125	40	125	None

The depth of liquid did not seem to have any important effect on the process of reduction.

INFLUENCE OF TEMPERATURE ON THE REDUCTION OF NITRATES INDUCED BY SEED.

The previous experiments reported were carried out at the temperature of the laboratory, about 75–80° in the day time. The temperature of the soil at the time wheat is planted, late in the fall or early in the spring, is much lower. If the reduction of nitrates induced by seed under laboratory conditions is also induced under field conditions, such a reduction might be expected in the late fall or early spring. The planted seed requires some time to germinate, after which, in the case of winter grain, comes a period of inactive growth. Excess of precipitation at these periods is also more likely to create anaerobic conditions in the soil, especially in localities of poor drainage, than at any other time. It seemed desirable, therefore, to determine how the process of reduction would be affected by a temperature approximating the temperature of the soil in late fall or early spring. With this point in view, two beakers containing two grams of wheat seed and 200 cc. of a 1000 p.p.m. sodium nitrate solution were placed in the ice box with a temperature of about 50° F. In Table 6 the results obtained from these beakers are compared with those obtained from two identical beakers kept at laboratory temperature. The temperatures of late fall and early spring, as indicated by this experiment, would not in themselves essentially interfere with the reduction of nitrate induced by seed. It would seem that the only effect of the lower temperature was to retard the process of reduction which otherwise followed its normal course.

TABLE 6.—*Influence of temperature on the reduction of nitrates induced by seed.*
(Parts per million of NO_2.)

Temperature of	After 2 days.	After 3 days.	After 5 days.	After 7 days.	After 8 days.	After 10 days.	After 12 days.	After 14 days.	After 16 days.	After 17 days.	After 19 days.	After 22 days.
Room.....	30	70	120	100	12	90	None	....	....	....	....	....
Room.....	50	80	137	5	6	90	None	....	....	....	....	....
Ice box....	2.5	50	100	90	120	80	120	225	320	200	120	Trace
Ice box....	2.0	40	80	80	120	70	120	320	400	240	48	Trace

TABLE 7.—*Influence of destroying the vitality of the seed on the reduction of nitrates as compared to that induced by growing seedlings.*
(Parts per million of NO_2.)

Material.	After 1 day.a	After 3 days.b	After 4* days.a	After 5 days.b	After 6* days.a	After 8 days.c	After 11 days.c	After 16 days.d	After 17 days.a	After 20* days.c	After 22 days.d
Sterile seed	3.5	20	12	40	12	40	40	11	15	14	10
Sterile seed	8.0	24	16	40	8.0	32	20	8	12	9	10
Growing seedlings	Trace	4	2.5	8	3.2	20	16	1.5	1.2	1.0	1.6
Growing seedlings	Trace	9	3.6	12	6.4	24	28	3.2	2.0	1.6	.....

* Solution not changed. (*a*) One day period. (*b*) Two days period. (*c*) Three days period. (*d*) Five days period.

INFLUENCE OF DESTROYING THE VITALITY OF THE SEED ON THE REDUCTION OF NITRATES AS COMPARED WITH THAT INDUCED BY GROWING SEEDLINGS.

The cause of the reduction of nitrates in the case of growing seedlings had been considered to be different from that obtaining in the case of ungerminated seed. It was thought to be a phenomenon directly connected with the metabolic processes of the growing seedlings.(4) It has been shown by the writer,(5) however, that microorganisms are responsible for the reduction of nitrates in the case of growing seedlings, as well as in the case of ungerminated seed.

As in the case of ungerminated seed, the contribution of the seedlings to the process of reduction is the supply of food materials contained in the mother seeds which is utilized by the reducing organisms. The growing seedlings and the reducing organisms are consequently drawing upon the same source of food. This would suggest the possibility of a competition for food between the growing seedling and the reducing organisms. The growth of the seedlings, therefore, would be expected to interfere with the process of reduction were it not for the possibility that the competition for food which they offer is offset by the increased solubility of the storage products contained in the mother seeds as a result of the processes of growth. It was the object of this experiment to determine whether the growth of seedlings actually has any inhibitive effect on the reduction of nitrates under laboratory conditions.

In the previous experiments the seeds were prevented from germinating by being kept submerged under a deep layer of water, usually 6.5 cm. The results obtained under these conditions could hardly

be compared wit[illegible] owing seedlings, in which case it would be necessary to keep the mother seeds just on the surface of the experimental solutions. The only way to prevent seed from germinating when kept on the surface of the experimental solution was to destroy its vitality. This result was accomplished by subjecting the seed to prolonged dry heating at a temperature of about 100° C.

The heated and unheated wheat seed in quantities of 5 grams was spread out on floating aluminum disks in agate-ware dishes, each containing 1500 cc. of a 1000 p.p.m. solution of sodium nitrate.

The experiment was begun January 17. The first nitrite determinations were made January 18. Germination was seemingly complete on January 20 when the ungerminated seeds in the dishes of the unheated series were removed. The maximum number of seeds which failed to germinate in one dish was 35. Enough seedlings were removed from the second dish of the same series to make a total of 35 with the number of removed ungerminated seeds. Thirty-five seeds were removed from each of the two dishes of the heated series. The quantity of seed was thus essentially the same for every dish. The solutions were usually changed after every determination, in order to prevent any too extensive changes in the concentration of the solution as a result of the growth of the seedlings. The figures in Table 7, therefore, represent not the continuous accumulations of nitrites, as in the previous tables, but accumulations during periods between the dates of two determinations.

The results (Table 7) show that the sterile seed produced more nitrites than did the growing seedlings in every case save one. This exception may be safely disregarded in view of the general character of the experiments previously noted. The heated seed produced larger quantities of nitrites even in the first 24 hours and before the germination of the unheated seeds seemingly could have gained much headway. The decided drop in the production of nitrites induced by the growing seedlings, beginning February 2, occurred about the time that the hulls of the mother seeds were practically emptied of their storage products.

There was a possibility that the greater production of nitrites in the case of the heated seed was due to the effect of heating on the food materials contained in the seed. When compared under the usual conditions in beakers, however, the heated seed failed to produce more nitrites than the untreated seed. It would seem, therefore, that the depressed reduction observed in this experiment was due to the growth of the seedlings, as was expected on the basis of theoretical considerations.

The tendency revealed by this experiment, should it prove to hold true under field conditions, might have some bearing on our agricultural practice. A high sterility in the seed used for planting might not only cause waste of planting material, but also, under certain conditions, a greater reduction of the nitrates present in the soil.

Influence of Soil on the Reduction of Nitrates Induced by Sterile Seed and Growing Seedlings.

The soil used was a silt loam from the Arlington farm. It was mixed with about 30 percent of sand in order to facilitate leaching. One hundred and fifty gram portions of this mixed soil were weighed into wine glasses with perforated bottoms. The bottom perforations were fitted with cork stoppers. Wheat seed was germinated on aluminum disks, the devitalized seed being kept under the same conditions. After the seed had germinated, the seedlings and sterile seeds were transferred to the glasses with the soil, 12 to each glass. All were planted at approximately the same depth. A 1000 p.p.m. solution of sodium nitrate was added to the glasses until it began to drain through the perforations in the bottoms. The perforations were then stoppered with the corks. A small quantity of solution was allowed to stand on the surface of the soil. The glasses were then placed on small glass rings in beakers. In each case the nitrites represent accumulations of approximately 24 hours. When determinations were to be made the corks were removed, the free solution allowed to drain, and their several successive portions of distilled water or fresh sodium nitrate solution passed through the soil in the glasses. The nitrites were then determined in the total leachings. Naturally sterile seed, picked out from the aluminum disks on which seed was allowed to germinate, was used, in addition to that made sterile by heating. The eight glasses of the experiment were treated alike in every case and the results are fairly comparable. The seed and seedlings were transferred to the soil January 18 and the leachings were collected periodically until February 21. The results are given in Table 8.

The high figures of the first readings may be attributed to the available food material originally present in the soil. The check glasses, which contained only soil and the nitrate solution, gave 14 parts per million of nitrites. When this amount is subtracted from the readings of this date, the results approach normal. It is shown clearly that the presence of soil did not interfere with the general tendencies exhibited in these experiments. The glasses containing the seedlings produced more nitrites than the check glasses and

glasses with the sterile seeds produced more nitrites than those containing the growing seedlings.

TABLE 8.—*Influence of soil on the reduction of nitrates induced by sterile seed and growing seedlings.*

(Parts per million of NO_2.*)

Material.	After 2 days.	After 7 days.	After 10 days.	After 11 days.	After 18 days.	After 19 days.	After 23 days.	After 25 days.	After 28 days.	After 31 days.	After 34 days.
Growing seedlings....	20	6.0	Trace	Trace	0.6	Trace	Trace	0.3	1.6	0.8	0.6
Growing seedlings....	16	2.4	0.7	0.8	0.4	Trace	Trace	0.3	0.8	Trace	Trace
Heated seed.........	35	12	2.5	7.2	6.0	2.5	1.0	0.5	3.5	4.0	3.0
Heated seed.........	30	40	2.5	6.0	8.0	3.5	2.0	0.6	6.0	5.0	3.0
Naturally sterile seed..	....	8.0	1.7	1.6	3.2	3.0	12.0	5.0	10.0	4.0	1.2
Naturally sterile seed..	....	16.0	1.4	1.6	8.0	3.5	20.0	6.5	10.0	6.0	2.0
Check...............	14	1.2	0.7	0.8	0.3	Trace	Trace	0.3	0.4	Trace	Trace
Check...............	14	Trace	1.4	2.4	0.6	Trace	Trace	0.3	0.5	Trace	Trace

* Each determination represents an accumulation during a period of approximately 24 hours.

The results of this experiment emphasize the possibility that young growing seedlings and especially ungerminated seed might cause reduction of nitrates in the field under certain conditions.

IS NITROGEN LOST IN THE SEED-INDUCED PROCESS OF REDUCTION OF NITRATES?

The process of reduction in these experiments was generally followed up to the disappearance of the nitrites. The natural query that suggested itself was, What becomes of the nitrogen of the reduced nitrates? Is it merely converted into other forms or is it wholly or partially lost? It was the object of the following experiment to throw some light on this point.

Approximately 2 grams of wheat seed was weighed into Kjeldahl flasks. Fifty cubic centimeters of a half percent solution of sodium nitrate was measured into each flask. There were two sets of Kjeldahls. One set was used only for testing for nitrates and nitrites. When the nitrates and nitrites had disappeared in this set, the Kjeldahls of the other set were allowed to stand a few days longer and then the nitrogen in them was determined by the ordinary Gunning method. Nitrogen was determined in the original seed and in the original solutions. Nitrogen was also determined in seed kept in 50 cc. of distilled water in Kjeldahls under the same conditions and for the same length of time as in the case of the experimental Kjeldahls. The experiment was carried out in triplicate. The results are given in Table 9.

There being no essential difference in the nitrogen content of the untreated seed and that of the seed kept in distilled water, the average of the six determinations was taken as the nitrogen content of the original seed and was used in calculating the theoretical nitrogen content of the seed in the experimental Kjeldahls. These estimated nitrogen values, increased by the average nitrogen content of the original nitrate solutions, ought to have approached closely those actually found in the experimental Kjeldahls, had no nitrogen been

lost in the process of reduction. However, the actual nitrogen values, as determined by analysis, fall below the theoretical values, indicating a loss of nitrogen almost equal to the entire nitrogen content of the nitrate solutions. This experiment was repeated with ground wheat seed. The results obtained exhibited the same tendency.

TABLE 9.—*Loss of nitrogen in the process of reduction of nitrates induced by seed.*

	N. in original seed.			N. in experimental Kjeldahls				
	N. in untreated seed. Percent.	N. in seed kept in distilled water. Percent.	N. in original solution. Mg.	Wt. of seed. Gms.	N. in seed (calculated). Mg.	N. in seed plus N. in solution. Mg.	N. actually found. Mg.	Loss of N. induced by seed. Mg.
1	1.93	1.90	39.58	2.0184	38.75	78.56	44.63	33.93
2	1.86	1.86	39.99	2.0036	38.47	78.28	41.26	37.02
3	1.90	1.80	39.86	2.0210	38.61	79.62	36.77	42.85
Average	1.92		39.81	......	.....	.....	.....	.....

The results of these experiments show that there are certain conditions under which nitrogen is actually lost in the process of reduction of nitrates, emphasizing the possible bearing of the seed-induced reduction of nitrates on the nitrogen economy in crop production. Should the tendency revealed in these experiments hold true under certain field conditions, it would mean not only a change in the form of nitrogen occurrence but also a possible loss of nitrogen.

REDUCTION OF NITRATES INDUCED BY ORGANIC FERTILIZERS.

By way of comparison, organic fertilizers were tested for their power to cause reduction of nitrates. The imposed conditions were similar to those of the seed experiments: 2 grams of substance; 200 cc. of solution; concentration of sodium nitrate, 1000 p.p.m. The experiment was begun July 18 and concluded July 25. The results are given in Table 10.

TABLE 10.—***Reduction of nitrates induced by organic fertilizers.***

(Parts per million of NO_2.)

Organic fertilizers.	After 1 day.	After 2 days.	After 3 days.	After 4 days.	After 5 days.	After 7 days.
Cotton seed meal	20	120.0	150.0	150.0	80.0	Trace
Cotton seed meal	50	100.0	150.0	200.0	225.0	Trace
Raw bone meal	14	7.5	2.0	8.0	12.5	8.0
Raw bone meal	12	6.0	2.0	6.0	10.0	10.0
Steamed bone meal	40	150.0	40.0	Trace	Trace	Trace
Steamed bone meal	30	125.0	80.0	Trace	Trace	Trace
Tankage	50	31.0	Trace	Trace	Trace	Trace
Tankage	50	5.0	Trace	Trace	Trace	Trace
Dried blood	30	50.0	Trace	Trace	Trace	Trace
Dried blood	30	125.0	Trace	Trace	Trace	Trace
Wheat seed	2.4	50.0	87.0	50.0	3.0	Trace
Wheat seed	2.4	50.0	75.0	50.0	3.0	Trace

The intensity rate of the reduction phenomenon is to be judged by the disappearance of the nitrites. The figures for raw bone meal after the first 24 hours already mark a decline of the nitrites, the maximum accumulation having occurred some time during this period. Accordingly, the organic fertilizers, with the exception of cottonseed meal, induced a much higher rate of reduction than the wheat seed. The higher rate of reduction induced by the organic fertilizers was probably due to the greater immediate availability of the nutrients which they contain. The original contamination may also be a factor.

In case the organic fertilizers should exhibit a similar behavior under field conditions, certain modifications of our agricultural practices would suggest themselves. For instance, it may not be advisable to apply nitrates simultaneously with organic fertilizers.

DISCUSSION OF EXPERIMENTAL RESULTS.

All the results reported here were obtained under laboratory conditions. Such results have the general disadvantage of not justifying the drawing of unqualified conclusions with any degree of safety until they are verified under field conditions. The verification in this case will present a difficult problem. Conditions approaching those of the soil experiments reported here undoubtedly occur in some fields, especially between late fall and early spring. The principal difficulty is the demonstration of the tendency. The lowest concentration used in this experiment was 100 parts per million of sodium nitrate. Such concentrations occur in soils, but they belong to the category of high concentrations. Furthermore, these concentrations seldom occur during the seasons which are favorable for denitrification, and the amount of organic matter added to the soil as dead seed and organic fertilizers is small when compared with the quantities used in these experiments. Small differences in the nitrate content of soils are not easily demonstrated, nor is it easy to demonstrate a response in yield to small differences in the nitrate content of soils.

The overcoming of these difficulties will be left to future experiments. The discussion at present must be limited to theoretical considerations. It is safe to assume that under the proper combination of circumstances the presence of additional organic matter would cause additional denitrification. It is to be expected that the denitrification under favorable field conditions would be in a measure proportionate to the added amount of organic material. Small additions of organic matter would be expected to result in a small amount of denitrification. Should this denitrification follow along the same lines of development as in the case of the laboratory

experiments, it would result in the loss of a certain amount of nitrogen. This amount may be small, but it is a loss and should be avoided if possible.

The question consequently centers itself on the fate of the final decomposition products of the reduced nitrates. If the reduction stops at the nitrite stage or if the nitrogen is converted into some form of organic matter, it would be eventually nitrified again. Should the ultimate product of reduction be ammonia, the chances of any nitrogen loss would be small. The ammonia would be arrested by the soil solution and by the soil acids. A loss of nitrogen would result only in case the ultimate product of reduction were elemental nitrogen. The experiments reported here leave open the question as to whether the lost nitrogen escaped as ammonia or elemental nitrogen. A German investigation (6) which came to the attention of the writer after this work had been completed, however, seems to have solved the question by proving the second hypothesis.

Aside from the question of loss, the change of form in itself is an important consideration. Nitrates are applied when it is desired to supply immediately available nitrogen. Any change from this form would partly defeat the object of the application.

While it is left for the future to define the actual rôle played by the denitrification caused by seed, certain precautionary measures may now be adopted. When practicable no nitrates should be applied at the time of planting, but rather late in the fall or early in the spring in the case of the winter crops. Preliminary results obtained at Arlington seem to favor such a practice. No nitrates should be applied simultaneously with organic fertilizers, especially at periods when the creation of anaerobic conditions by heavy rainfall may be expected. The possibilities suggested by these experiments may be used as additional reasons for making every effort to obtain seeding material of the highest vitality. They may also serve as additional reasons for thorough soil drainage.

SUMMARY.

Reduction of nitrates is induced by seed under laboratory conditions.

The quantity of seed, the basic radicles of the common nitrates, the concentration of the nitrate solution, and the depth of the liquid in which the seed is submerged did not essentially affect the course of the process within the limits of these experiments.

At a temperature of about 50° F. the process of reduction was somewhat retarded; otherwise, it followed its normal course.

Growing seedlings produced a smaller quantity of nitrites than seed which had been devitalized by heating. The most plausible explanation of this phenomenon would seem to be the competition between the growing seedling and the reducing organisms which are directly responsible for the reduction of nitrates for nutrients stored up in the mother seeds.

Young seedlings induced reduction of nitrates when grown in soil. Seed devitalized by heating, as well as that naturally sterile, produced an appreciably larger quantity of nitrites than the growing seedlings under the same conditions.

Actual loss of nitrogen was demonstrated as a result of reduction of nitrates caused by seed.

LITERATURE CITED.

1. SCHÖNBEIN, C. F. Ueber einige chemische Eigenschaften der Pflanzensamen. *In* Jour. für Prakt. Chem. 3:214. 1868.
2. MOORE, BENJAMIN. Photosynthetic processes in the air upon the land and in the sea in relation to the origin and the continuation of life on the earth. Jour. Chem. Soc. (London) vols. 119 and 120, no. 708. 1921.
3. THATCHER, R. W. The chemistry of plant life. McGraw-Hill Book Co., New York. 1921.
4. LAURENT, M. E. Experiences sur la reduction des nitrates par les vegetaux. *In* Ann. Inst. Pasteur. 4:722. 1890.
5. DAVIDSON, J. Do seedlings reduce nitrates. *In* Jour. Biol. Chem. 37:143. 1919.
6. OELSNER, ALICE. Ueber Nitratreduction in nassem Ackerboden ohne Zusatz von Energiematerialen. *In* Centr. Bakt. Parasitk. Abt. 2, 48:210–221. 1918.

FUNGI INTERNAL TO MISSOURI SEED CORN OF 1921.[1]

B. B. BRANSTETTER[2]

Since corn root rot has become widespread over the State of Missouri it would seem interesting to compare the species of fungi found in seed corn from Missouri with the fungi found by investigators in seed corn of other states. Hoffer and Holbert, (1)[3] in 1920, reported two species of *Giberella* to be most prevalent in Indiana and Illinois corn. Valleau, (2) in 1920, found *Fusarium moniliforme* in every sample of corn that he tested. Manns and Adams, (3) in 1921, isolated four organisms, *Diplodia zeae, Giberella saubinetii, Fusarium moniliforme,* and another organism thought to be *Cephalosporium sacchari* from Delaware seed corn.

[1] Contribution from the Department of Botany, University of Missouri, Columbia, Mo. Received for publication November 9, 1922.

[2] Instructor in Field Crops.

[3] Reference by number is to "Literature cited," p. 357.

One of the first tasks undertaken in the study of corn root rot at the Missouri Experiment Station was to make a statewide survey of the fungi internal to the seed corn. County agents and farmers were asked to send in four ordinary seed ears; two with clean, white butts and sound tips, and two with black, brown or reddish discolorations in the butt end of the cob and with discolored and slightly molded tips. Samples of 1921 seed corn were received from forty-nine counties, including all the leading corn-growing counties in the various sections of the State. As each sample arrived the two apparently diseased ears were numbered 1 and 2. The two remaining ears, though in most cases not clean or disease-free in the writer's judgment, usually bore disease symptoms in a less marked degree, and were numbered 3 and 4. Eight kernels, located spirally from butt to tip, were removed from each ear. Approximately the tip one-sixth of each kernel was cut off with a scalpel, and surface sterilized in mercuric chloride solution (1 : 1000). After thoroughly washing with sterile water the tip was planted in Petri dishes on ordinary potato-dextrose agar, four tips per plate. The plates were incubated 20 to 30 days at room temperature or about 25° C. More than one organism grew out of many kernals. Every possible combination of two of the organisms listed in Table I was observed from a single kernel. In some cases *Diplodia zeae* appeared followed by *Fusarium moniliforme*, but in most cases a *Fusarium* colony was followed with a growth of *Cephalosporium*. In all such cases, where more than one fungus grew out of a single kernel, only the organism that appeared first was counted. Table 1 shows the relative occurrence of the three species of fungi as found in Missouri seed corn.

TABLE 1.— *Showing relative occurrence of fungi found in seed corn.*

		Fusarium moniliforme			*Cephalosporium sacchari*			*Diplodia zeae*		
	Number of ears	Number of isolations.	Percent of isolations.	Percent of ears infected.	Number of isolations.	Percent of isolations.	Percent of ears infected.	Number of isolations.	Percent of isolations.	Percent of ears infected.
Ears 1 and 2.....	98	319	40.7	79.6	110	14	46.9	93	11.9	34.7
Ears 3 and 4.....	94	192	25.5	57.5	179	23.7	59.6	39	5.2	18.1
Total.......	192	511	33.3	68.8	289	18.8	53.1	132	8.6	26.6

The first group, or badly diseased ears, contained nearly twice as many kernels infected with *Diplodia zeae* and *Fusarium moniliforme* as the second group; but the latter group, or apparently disease-free ears, contained many more kernels infected with the third organism, called *Cephalosporium sacchari* because it resembles the organism given that name by Manns and Adams in Delaware. This can be explained by the fact that both *Fusarium moniliforme*

and *Cephalosporium sacchari* grew out of many plantings, but since the latter organism invariably appeared two to ten days later than *Fusarium moniliforme* it was not counted. Therefore, since ears 1 and 2 were so heavily infected with *Fusarium moniliforme* few kernels were left out of which *Cephalosporium sacchari* alone might grow. It is interesting to note here that only one culture of *Giberella saubinetii* was obtained from more than 1600 plantings.

After completing this test, the writer went thru the lot of ears and very carefully selected all the ears that appeared perfectly clean, healthy and sound. In this selection, in addition to selecting ears free from conspicuous molds or unsoundnesses, much care was taken to avoid brown, black, red or dark discolorations and the slightest signs of mold in the butt ends of the cobs and extreme tip of the cobs. The idea in mind was to select disease-free or nearly disease-free ears on the basis of external ear characters. How well this can be done is illustrated in Table 2; giving the number of fungous infections in disease-free ears selected after the manner described above compared with the fungous infections in a similar number of ears selected for their diseased appearance. The data in Table 2 were complied from the survey reported in Table 1.

TABLE 2.—*Showing relative infections of apparently sound and apparently diseased seed corn.*

	Disease record of ears selected as disease-free. Number of isolations from eight kernels.				Disease record of ears selected for diseased appearance. Number of isolations from eight kernels.		
Ear No.	*Fusarium moniliforme.*	*Cephalosporium sacchari*	*Diplodia zeae.*	Ear No.	*Fusarium moniliforme.*	*Cephalosporium sacchari.*	*Diplodia zeae.*
2.4	0	0	0	1.1	1	2	2
3.3	0	0	0	3.1	7	0	0
9.3	0	1	0	4.1	0	0	8
13.3	2	0	0	5.1	0	1	5
13.4	3	0	0	5.2	6	1	1
14.3	0	0	0	8.1	5	0	3
14.4	0	0	0	8.2	4	0	4
18.3	0	0	0	9.1	4	0	3
21.3	0	0	0	9.2	4	4	0
21.4	0	2	0	10.1	4	0	3
25.4	0	0	0	16.1	1	6	1
31.3	3	0	2	18.1	6	1	0
32.4	0	0	0	24.1	8	0	0
34.3	5	0	0	30.1	1	7	0
51.3	0	0	0	31.1	5	0	2
54.3	2	2	0	36.1	7	0	1
57.4	3	5	0	39.2	8	0	0
69.3	0	0	0	40.1	8	0	0
73.4	0	0	2	51.1	3	2	2
Total	18	10	4	....	82	24	35

It will be noted that only 19 of the 192 seed ears appeared completely clean, sound and healthy. Nine of these ears were disease-free in pure culture and only four ears showed as much as 50 percent infection; on the other hand, the ears selected for their diseased appearance generally showed 100 percent infection.

The disease survey shows that 1921 Missouri corn was heavily infected with *Fusarium moniliforme Cephalosporium sacchari* and *Diplodia zeae* in the order named; that kernels of many ears were infected with two species of the above named fungi; and, that with a little care one can select comparatively disease-free ears from a lot of corn thus eliminating the necessity of using the germinator as a means of detecting heavily infected seed ears.

LITERATURE CITED.

1. Holbert, J. R., and Hoffer, G. N. Control of the root, stalk, and ear rot diseases of corn. U. S. Dept. Agr. Farm. Bul. 1176. 1920.
2. Valleau, W. D. Seed corn infection with *Fusarium moniliforma* and its relation to the root and stalk rots. Ky. Agr. Exp. Sta. Bul. 226. 1920.
3. Manns, T. F., and Adams, J. F. Corn root rot diseases. Del. Agr. Exp. Stat. Bul. 128. 1921.

BOOK REVIEW.

Reminiscences, Tales and Anecdotes of the (Rothamsted) Laboratories, Staff and Experimental Fields, 1872–1922.

By Edwin Grey. Rothamsted Experimental Station. 1922. 155 p., illus.

In 1872, twelve-year-old Edwin Grey was one of several village boys employed at Rothamsted to separate grasses, clovers and weeds from samples of hay. This "grass-picking" coming to an end, Dr. Gilbert told him he "had better go back to school for a bit and if there should be a vacancy" he would let him know. About a year later the vacancy occurred and from that time to the present the author of this book has been on the permanent staff, rising step by step to finally become superintendent of field plots. After this fifty years' connection with Rothamsted, he has prepared this interesting volume of reminiscences, having the aid of neither diary nor notes.

"Mr. Grey deals with the more personal side of Rothamsted, with the doings of the men themselves . . . down to the humblest worker on the plots or in the laboratory . . . This he has set down in his own kindly, humorous manner, and from his record nothing has been deleted nor has there been any editorial polishing. The record stands as he wrote it, a faithful account of the men and boys who executed the great work which Lawes and Gilbert planned." (From Preface by Sir Edward Russell.)

Young Grey was placed under Willis "who was highly esteemed by Sir Henry and consulted by him in all things appertaining to the experiments". At certain times of the year Willis "made very

voluminous notes" on the crops; "in fact the more he made and the longer they were, the more was Sir Henry pleased". Accounts of Sir John Lawes' evening practice of going about the experimental fields "with long spud in hand" observing the plots, or of Sir Henry's extreme care in giving "instructions as to any special work to be undertaken, very seldom verbally, generally by dictation." and having these then read back to him, vie in interest with those of Gifkins, who "worked in the laboratory in the morning, and . . . with Sir Henry in his study at night, sometimes until the early hours of the morning," and as clerk of the parish church received callers at the laboratory who came to register births or deaths, or with those of Frank, the "experimental farm man" who had been on this work from the commencement of the experiments in 1843 and who occasionally on Sundays could be seen walking and chatting with Sir John on their way home from church, both passing away in the same year (1900).

The solemnity and seriousness of the occasion when later the author descended with Warrington into a hole on the plots to assist in the taking of soil samples for nitrification investigations — "all done in utter silence and hardly breathing" is in contrast with his recollections of "Professor" King, an early caretaker and ashburner in the laboratory, who often used the stick on the young grass-pickers and at the Harpenden annual races came forth in gray silk hat to assist in the starting of the horses.

The experimental fields and the methods of handling the land, harvesting and threshing the crops receive much attention. On lonely Hoosfield a laborer, who spent nearly all his time there weeding, etc., until he had become "fed up" with the monotony and talked to himself for company, was overheard by the boy complaining "I can't stand it. No, nor I won't either. I can't stick it. I shall tell him (Sir John) I can't put up with it." On Broadbalk, the world-famous wheat field, Sir John first tried using school girls to pull the grass between the wheat rows, counting upon their having keener eyesight and being more careful than boys. "Oh! those girls were artful. One day as I was passing near the field, I noticed them jumping and skipping about; when nearer I stood and watched these unusual movements. I then could see that the fore-girl was teaching the others how to dance the keel-row. They were linking arms and twisting around, in fact having a regular Highland Fling. I thought what about the poor wheat plants. However, it soon recovered from the severe trampling looking none the worse."

Even the fields had war experiences, a bomb from a Zeppelin striking plot No. 6 in Broadbalk, making a hole 11 feet deep and 18 feet across and burying the wheat shocks standing on either side. On November 11, 1918, a number of German prisoners were assisting in lifting mangolds on the Barnfield plots when near noon, being beyond the sound of whistles and bells, a messenger brought word that the armistice was signed. All except the prisoners joined hands and sang the national anthem. "One of the men named Lawrence called to them (the prisoners), 'Come in along with us.' They at once came in and joined hands."

The book should be read by everyone who wishes "a picture of the machine at work, with the boys gradually being licked into shape as they grew up, until they too had absorbed the high traditions and could be left in charge of the most important operations with the certainty that it would be well done." (From Preface).—F. J. A.

AGRONOMIC AFFAIRS.

MINUTES OF THE ANNUAL MEETING.

Following are the minutes of the fifteenth annual meeting of the American Society of Agronomy, held at Washington, D. C., on November 20 and 21, 1922.

Morning Session, Monday, November 20, 1922.

The Society was called to order at 9:30 A. M. by President L. E. Call, of the Kansas Agricultural College, in the New Ebbitt Hotel. Over one hundred and fifty members were present. The session consisted in a symposium on phosphorus arranged by Dr. F. E. Bear of the Ohio State University. The following papers were presented:

The Effects of Phosphate on Early Growth and Maturity, Prof. Chas. F. Noll, Pennsylvania State College, State College, Pa.

The Foraging Power of Plants for Phosphate Rock, Dr. F. C. Bauer, University of Illinois, Urbana, Ill.

Methods of Distribution of Phosphate Fertilizers, Prof. S. B. Haskell, Mass. Agr. College, Amherst, Mass.

The Necessity of Sulfur Carriers in Artificial Fertilizers, Dr. William Crocker, Thompson Institute of Plant Research, Yonkers, N. Y.

President Call announced the appointment of the following committees:

Nominating—Prof. C. A. Mooers, Dr. C. R. Ball, Dr. J. G. Lipman.

Auditing—Prof. Geo. Roberts, Dr. A. G. McCall, Prof. C. W. Warburton.

Resolutions—Dr. C. V. Piper, Dr. S. B. Haskell, Prof. M. F. Miller.

Afternoon Session, Monday, November 20, 1922.

Meeting called to order at 2:00 P. M. by President Call. One hundred and sixty-five present. Symposium on phosphorus continued. The following papers were presented:

Organic Phosphorus in Soils, Dr. Oswald Schreiner, Bureau of Plant Industry, U. S. D. A., Washington, D. C.

Chemical Analyses to Determine Phosphate Needs, Prof. Emil Truog, Univ. of Wisconsin, Madison, Wisconsin.

The Economic Use of Phosphate Deposits, Dr. W. H. Waggaman, Bureau of Soils, U. S. D. A., Washington, D. C.

President Call then called for the report of some of the standing committees of the Society.

In the absence of the Chairman, Prof. C. A. Mooers read the following:

REPORT OF THE COMMITTEE ON THE STANDARDIZATION OF FIELD EXPERIMENTS.

The committee recommends the adoption of the report made last year and published in Vol. 13, No. 9, page 368 of the Journal with the following minor modifications:

Page 369—Under "Uniformity of Soil", insert after first sentence, "A soil profile to the depth of three feet is highly desirable for each series of plots."
Page 370—Under "Uniform Stand of Plants", insert "tested" after first word of first paragraph.
Page 372—Under "The Plats" insert in second paragraph "Wherever possible the same number of series should be planted on each piece of land".
Page 372—Under "Replication of Plats" in fourth sentence change "May be reduced to any point considered necessary" to "may be considerably reduced".
Page 373—Under "Determining Yields" in the last line of the third paragraph under this head omit "in the case of late maturing varieties of".
Page 373—Under "The Publication and Interpretation of Results" the Society should decide whether or not methods of calculating probable error should be suggested.

It was moved and carried that the full report of the committee as published with the modifications suggested be adopted with the understanding that the change in the wording under "probable error" be considered by the Society at conclusion of the symposium on statistical methods.

The committee filed a complete BIBLIOGRAPHY ON FIELD EXPERIMENTS. (To be published later.—Editor.)

The COMMITTEE ON TERMINOLOGY reported as follows, Dr. Piper presenting the report:

Your committee begs to report that it has failed to accomplish what it hoped during the past year partly owing to the illness of its chairman. The aim of the committee, namely, a glossary of agronomic terms is now also an official desideratum of the U. S. Dept. of Agriculture, so that it is believed official aid can be secured for the committee's work. It is confidently believed that a preliminary glossary in multigraph form can be issued during the year 1923.

C. V. PIPER, *Chairman.*
C. R. BALL,
H. L. SHANTZ.

Dr. H. K. Hayes reported for the Committee on Varietal Standardization as follows:

REPORT OF THE COMMITTEE ON VARIETAL STANDARDIZATION.

The efforts of the Committee on Varietal Standardization have been carried on largely through correspondence. The subjects which have been discussed are listed under the following general headings:

1. Adoption of the best available varietal classifications.
2. Co-operation between experiment stations located in similar crop areas for the purpose of testing and of standardizing varieties.
3. The development of a method of registration of varieties so that new and valuable stocks may be better known and made available to more investigators.

The committee believes that the most recent and logical classification of any given crop should be adopted. Any particular classification, however, will be subject to continual revision. It is suggested that a committee of varietal classification (including terminology) be appointed. The suggested duties of this committee would be to act as a medium for the collection of criticisms regarding the working value of the classifications adopted, to suggest changes when such appear desirable and to aid in developing the classification of crop plants for which classifications are not now available.

Classifications of some of the farm crop plants have been made and these are now available. The Committee has examined these with a view to their adoption by the Society. It is the opinion of this Committee that the following varietal classifications should be adopted by the American Society of Agronomy: The classification of cultivated varieties of oats by Etheridge; the classification of commercial varieties of wheat by Clark, Martin and Ball; and the classification of cultivated varieties of barley of Wiggans.

For the purpose of showing the possibilities of co-operation in varietal experiments in those sections where such co-operative experiments are not yet established, a co-operative varietal trial was arranged with men in charge of farm crops in the following stations: Minnesota, North Dakota, South Dakota, Michigan, Wisconsin, and Iowa. The following farm crops were used in this co-operative study: oats, barley, spring wheat, winter rye, soybeans, and flax. To illustrate the work which is being carried on, a list of the varieties furnished by Mr. A. C. Arny of the Minnesota station and Mr. J. F. Cox of the Michigan station are given here:

Mr. A. C. Arny, University farm, St. Paul, Minn.

OATS
- Sixty Day, Minn. 674 (for the early oat sections)
- Minota, Minn. 512 (mid-season variety)

BARLEY
- Manchuria, Minn. 184

RYE
- Minnesota No. 2

SPRING WHEAT
- Marquis, Minn. Accession No. 1239 (Common)
- Mindum, Minn. 470 (Durum)

WINTER WHEAT
- Minturki, Minn. 1507

SOYBEANS
- Minsoy, Minn. 139 (early)
- Chestnut, Minn. 110 (medium)

Mr. J. F. Cox, East Lansing, Michigan.

OATS
- Wolverine

BARLEY
- Mich-2-row
- Michigan Black Barbless

BEANS
- Robust

SOYBEANS
- Manchu
- Ito San

Each of the men in charge of varietal experiments in the various states supplied similar lists of varieties of each of the various crops. Seed was then furnished other co-operators by each of the men who entered the co-operation. In several sections of the country similar co-operative varietal experiments have been arranged for by the United States Department of Agriculture. It is almost necessary that some central agency arrange for such co-operation, and for making the results available to all co-operators. It is the wish of the Society that other co-operative trials be arranged for by

the committee or should such co-operation be left to the officials of the U. S. Department of Agriculture and of various State stations?

While the adoption of the best available varietal classifications is now perhaps the most important work in varietal standardization this will not necessarily lead to the desired results without some further method of handling varieties. It is accordingly the opinion of your committee that the next important step which should be taken is the development of a method of registration of merit of new varieties which are of high performance or plant breeding importance.

A variety, in order to establish high performance, must have been tested in comparable replicated trials for a period of three to five years at a Federal or State experiment station. The variety must have a performance record significantly better than the standard commercial variety with which it has been compared.

To establish plant breeding importance, a variety must have some economic character in which it excells to such a degree that it is being used in hybridization for the purpose of combining in one variety this favorable character with other important characters.

It seems to the members of the committee that the logical place for registration of new varieties is the U. S. Department of Agriculture. The development of a new office for the handling of registration would necessitate a special appropriation, whereas the utilization of present offices would allow the work to be started in the near future. Classifications suggested for adoption include the cereal crops: wheat, oats, and barley. A good start could be made by having registration for these crops handled by the office of Cereal Investigations. We suggest the registration of all commercial varieties which are now included in the classifications which this committee has recommended for adoption by the Society. At the time of a request for registration of other varieties, the history of the variety must be given, including performance records and the commercial distribution or statements of the use and particular value of the variety to the plant breeder. Head and grain samples must be furnished and a suitable name suggested. We urge the use, by all workers, of the rules of nomenclature which have been previously adopted by the Society.

For the purpose of bringing these problems before the Society so that definite action may be taken and this important project may be started immediately, the following motions are made:

1. That the varietal classifications of wheat by Clark, Martin and Ball; of oats by Etheridge; and of barley by Wiggans, be adopted by the American Society of Agronomy.

2. That registration of varieties of wheat, of oats, and of barley be delegated to the office of Cereal Investigations.

3. That all commercial varieties now included in the classifications suggested for adoption be registered. That in submitting new varieties for registration the histories, head and grain samples, and performance record be furnished. That all varieties of high performance or plant breeding value (according to definitions given) be eligible for registration of merit.

4. That a committee be appointed with power to act for the purpose of drawing up detailed plans for registration and that these plans be published in the Journal of the American Society of Agronomy.

The following suggestion is made:

1. That a committee of varietal classification (including terminology) be appointed.

John H. Parker, H. K. Hayes, *Chairman.*
J. Allen Clark, R. G. Wiggans,
R. J. Garber, E. F. Gaines,
A. B. Connor, H. G. Hastings.

The report of the committee was received and adopted and the committee continued.

The report of the Committee on an Intercollegiate Grain Judging Contest was presented by Prof. J. H. Parker, as follows:

REPORT OF THE COMMITTEE OF AN INTERCOLLEGIATE GRAIN JUDGING CONTEST

In order to ascertain the attitude of the men responsible for crops teaching in the various Agricultural Colleges in the United States and Canada, a tentative plan was formulated and submitted to them in September and October of 1921, together with a questionnaire and a request for suggestions.

Questionnaires to the number of fifty-one were sent out and forty-one were returned, filled out and a number of suggestions accompanied them. Of this number twenty-five indicated that they would probably prepare judging teams in the event a contest were held in connection with the International Live Stock Exposition in 1922. A full report was read at the annual meeting in New Orleans in November, 1921. The report was accepted at that time and the committee continued.

The matter of holding a contest in 1922 was considered in conference with officials of the International Live Stock Exposition during the 1921 meeting in Chicago. That organization had been considering a contest previously and two men representing it were added to the committee.

The enlarged committee met immediately and discussed in detail the tentative plan. A number of suggestions were made. With all the suggestions in mind, another plan was formulated and sent out. A copy of the revised plan is attached.

At a meeting of the management of the International Live Stock Exposition, held early in 1922, it was thought best on account of lack of facilities not to attempt to hold a contest in December of this year. It was suggested that a contest be held at each institution as far as possible or that neighboring institutions arrange for contests.

A letter was sent out to each institution urging that this be done and that reports be sent to the chairman of the committee.

A. C. Arny, *Chairman.*
S. C. Salmon.
Joseph F. Cox.

The report of the committee was adopted and the committee continued.

Dr. J. G. Lipman made a brief report on the International Congress of Pedologists held in the spring at Prague. He suggested that for the next Congress, representatives of the American Society of Agronomy be chosen so that the Society might be officially represented.

Evening Session, Monday, November 20, 1922.

The annual dinner of the Society was held at 6:30 in the New Ebbitt Hotel.

President L. E. Call gave his presidential address on "Increasing the Efficiency of Agronomic Research."

The report of the Secretary was read and received. The report follows:

REPORT OF THE SECRETARY.

I beg to submit herewith the report of the Secretary for the past year.

Membership.—The membership of the Society has been increased to a very encouraging extent during the year, 197 new members being enrolled. This increase is due in large measure to the efforts of President Call, who, early in the year, secured the aid of a special representative of the Society in every State and in eight foreign countries, in enlarging the membership.

The Society is certainly much indebted to all these men for their efforts in its behalf and many might be mentioned who have secured several new members. The record goes to Dr. F. E. Bear of Ohio, who has sent in 36 names.

The Secretary has aided in some cases by circularizing the entire county agent list in the particular state and several hundred letters have been sent from his office in this connection. It might be well to mention here that several of the representatives have requested sample copies of the Journal to be utilized in their campaigns, but it has been impossible to comply with these requests owing to the fact that the supply of back numbers is not large enough to use in this way. It has been suggested that the Editor arrange for the printing of an extra large number of copies of some one or two issues, so that a supply may be available for distribution as sample copies. It would undoubtedly aid materially in securing new members if a sample of the Journal could be sent to each prospect. Whether or not the expense would be warranted is, of course, problematical.

At the present time the membership of the Society numbers 775 and there is a subscription list of 145. Fourteen new subscriptions have been added during the year and 10 have been withdrawn. Sixty-one members were dropped on January 1st, 52 for non-payment of dues and 9 for lack of correct addresses, and 27 resigned, making a total loss of 88. This leaves a net gain for the year of 109. On November 1, however, over 100 members have not paid their dues for the present year. Three notices have been sent out and possibly one more attempt should be made to secure the dues from these delinquents.

The method of sending the Journal for an entire year to all members, whether or not their dues are paid, means a considerable financial loss to the Society and the Secretary would urge that action be taken requiring the payment of dues by March 1st or the dropping of names at that time. This method is followed successfully in other societies. Reinstatement may be readily accomplished by the payment of back dues and members who really wish to stay in the Society will be anxious not to miss any issues of the Journal. Holding members on the rolls for a year, with dues unpaid, does not aid financially or in any other way as too large a proportion drop out at the end of the year. Those who do reinstate would be just as likely to do so earlier and less expense would be involved in collecting their dues.

Dues.—The announcement of the annual meeting of the Society called the attention of the members to the financial status of the Society and the desirability of increasing the dues in order not only to permit of paying the cost of the Journal as published at present, but also to provide for twelve issues instead of nine and for a larger Journal. At present there is an annual deficit of about $900 and frequently only seven or eight numbers are issued during the year. If the dues are increased to $5.00, it should be possible to publish twelve issues and if the income of the Society can be increased to some extent by advertising, it may be possible to get out a larger Journal.

Several members have written expressing their approval of an increase in dues and only one has been opposed. It seems probable that a large part of the present membership can be retained even with a larger fee.

Advertising.—The inclusion of advertising in the Journal was discussed at the last annual meeting of the Society and the matter was left in the hands of the Executive Committee. In the summer it was put up to the Secretary and early in September correspondence was taken up with various commercial concerns. An original letter has been sent to each company, presenting the claims of the Society, urging the desirability of placing advertising in the Journal and setting forth the price of space, this being fixed by the Editor. The number of letters sent out may be seen from the following figures:

Fertilizer Companies	436
Chemical Supply Houses	14
Seed Companies	11
Farm Machinery Companies	6
Legume Culture Companies	6
Lime Companies	7

It is too soon to give results as many of these letters have been sent out rather recently. Four advertisements have been secured and several companies have indicated that they would take up the matter the first of the year when their new advertising appropriations became available. It is hoped that considerable revenue may be secured from this source.

Meetings.—After considerable difficulty a program was arranged for a winter meeting of the Society at Toronto last year, with the American Association for the Advancement of Science. A report of this meeting has been made in Science and some of the papers presented have been published. It was a most successful meeting with a good attendance.

Resolutions adopted at that meeting pertaining to the continuance of the Journal of Agricultural Research and the Experiment Station Record were transmitted to the Chairmen of the Congressional Committees on Agriculture and courteous replies were received. A resolution urging affiliation of the Soil Survey Workers' Association with the Society was also adopted and has been forwarded to that Association.

A meeting has been arranged to be held this winter at Boston with the A. A. A. S. under the general charge of the New England Section of the Society. Director S. B. Haskell is acting as the representative of the Society and a symposium on Soil Toxicity has been arranged by Dr. B. L. Hartwell. The meeting is to be held on Friday, December 29th, and a joint dinner with Section O (Agriculture) will take place on Thursday evening.

The matter of the annual meeting of the Society will be taken up by President Call who has had considerable correspondence in regard to it. Invitations have been received by the Secretary from San Francisco, Chicago and

West Baden, Indiana. The A. A. A. S. meets next year at Cincinnati and there is some possibility of the Federation of Biological Societies meeting at some other place.

The Society was invited to sponsor the Lime Conference held by the Tennessee Agricultural Experiment Station at Knoxville, Tenn., early in September, but unfortunately none of the officers of the Society were able to attend. The meeting was undoubtedly a most enjoyable one.

The Federation of Biological Societies.—Upon invitation of the National Research Council the Secretary attended a meeting at Toronto where the proposal for a Federation of Biological Societies was discussed. At a later conference held in Washington in April, the Society was represented by President Call who will undoubtedly have a special report to make. The action of this meeting together with the proposed Constiution of the Federation have been published in Science. The Society should consider whether or not it will affiliate with the Federation.

Constitution Revisions.—At the last annual meeting a proposal was made to revise the constitutional provisions for the election of officers. After considerable correspondence the following new clauses of the Constitution are suggested:

Article VI. The officers shall consist of a President, a Secretary-Treasurer and an Executive Committee composed of one member from each geographical section of the Society, the two officers mentioned and the Presidents of all affiliated societies as ex-officio members.

Article VII. The duties of these officers shall be those usually pertaining to their respective offices. The term of the President shall be for one year or until his successor has been elected. The members of the Executive Committee shall be elected for such a term of years that one member will retire annually. The Secretary-Treasurer shall be appointed by the Executive Committee.

Distribution of Journals.—The entire reserve supply of back numbers of the JOURNAL was shipped to the Secretary by Prof. Warburton early in the year and are now available for distribution from his office. Many copies have been sold during the year but it is no longer possible to supply complete sets as one number of Volume VIII is exhausted. Several other numbers of the same volume will very soon be out. The practice of selling these Journals at a reduced price to members has been continued and this plan will undoubtedly be followed unless the Secretary receives other instructions from the Society. Six complete sets of the JOURNAL except for No. 4 of Volume VIII were sent without charge to the American Committee to aid Russian scientists. This action was taken upon the order of the Executive Committee.

In conclusion the Secretary would express his indebtedness to all those who have so cordially supported the work of his office during the year and especially the aid and support given by President Call and Editor Thatcher who have maintained a prompt and extensive correspondence with him throughout the year.

Respectfully submitted,

P. E. BROWN, *Secretary.*

The report of the Treasurer as follows was read and received:

REPORT OF THE TREASURER.

I beg to submit herewith the report of the Treasurer for the year:

RECEIPTS.

Balance last report	$883.14
Journals sold	201.08
Reprints sold	320.39
Dues 1921 and older	77.00
Dues 1922	1,328.53
Dues, new members, 1922	588.40
Subscriptions 1921 and older	74.20
Subscriptions 1922	252.37
Subscriptions, new, 1922	37.30
Dues and subscriptions 1923	27.30
Life membership	50.00
Refund on JOURNAL (from printer)	40.02
Refund on freight	16.90
Texas Associate Members (11)	5.50
Total receipts	$3,902.13

DISBURSEMENTS.

Printing the JOURNAL, Reprints, Halftones, etc., (9 issues September, 1921–September, 1922, inc.)	$3,211.97
Miscellaneous printing, (letterheads, envelopes, programs, etc.)	134.25
Stamps	95.00
Freight and express, (reserve supply JOURNALS)	182.10
Miscellaneous items, (telegrams, refunds, exchange on checks, etc.)	39.93
Total disbursements	$3,663.25

Receipts	$3,902.13
Disbursements	3,663.25
Balance on hand	$238.88

Respectfully submitted,

P. E. BROWN, *Treasurer.*

The report of the Editor was presented as follows:

REPORT OF THE EDITOR.

After a rather inauspicious beginning, the work of editing and publishing the 1922 volume of the JOURNAL of the American Society of Agronomy has proceeded very satisfactorily.

When I assumed the editorship of January 1st, I found that neither the November nor the December issues for 1921 had yet been received from the printers and that there were likely to be long delays in getting future issues through the presses of the company which had been publishing the JOURNAL for several years. For this, and other reasons, I decided to solicit bids for the printing and distribution of the JOURNAL from other concerns; with the

result that a contract was entered into with the present publishers, on somewhat more favorable terms than have prevailed in former years and with a guaranty of prompt publication.

The material for the January issue having gone forward to the former publishers and being long delayed by them, it was deemed wisest to regard this as a combined January–February issue and to make the March issue the first one to be distributed under the new contract. This issue came out promptly on March 15th. Unfortunately, the former publishers were not able to get the January–February issue into the mails until March 21st, and considerable confusion resulted. However, from that time forward the succeeding issues were distributed promptly and in regular order.

Further, a new mailing system was inaugurated with the change in publishers, the mailing list was carefully corrected up to date and is now easily kept correct by changes each month. So far as I am aware, the whole matter of the actual publication and distribution of the JOURNAL is now proceeding very satisfactorily, and at approximately 15 per cent less expense to the Society than in former years.

The former editor, Mr. C. W. Warburton, turned over to me twenty-three manuscripts of papers which had accumulated in his hands since December, 1920, and the Secretary of the Society sent to me nineteen other papers which had been read at the New Orleans and Toronto meetings in 1921. This appeared to offer more material than could be used in the Journal for a year to come. However, four of the MSS. were subsequently withdrawn by their authors and three were considered by the editorial board as not suitable for publication in the JOURNAL. Twenty additional papers have been received from their authors during the year, of which sixteen were accepted for publication. In several cases, authors were requested to condense or abridge their manuscripts, and in every case where it could be done without seriously lessening the efficiency of the presentation, illustrations were omitted, so as to reduce the cost of publication.

The final result is that all except three of the papers which have been accepted have appeared in the JOURNAL. It is hoped that these three and the President's annual address which is to be read at this meeting can be printed in the December issue of the JOURNAL; so that the Society's publication duty may be said to have been completely fulfilled, and we will be able to begin with the January issue the publication of the papers which are presented at this meeting.

The report of the Secretary-Treasurer will show that this result has been secured only by creating a deficit in the treasury of the Society. This situation was foreseen a year ago and the problem of more adequate financing was discussed at the New Orleans meeting, at which time the question of admitting advertising to the JOURNAL, as a means of increasing our revenues, was referred to the Executive Committee with power to act in the matter. After the situation became acute, the committee authorized the soliciting of advertising by the Secretary, and a small amount has been secured and used in the last three issues of the JOURNAL. The revenue from this source has been small as yet, but there are favorable indications that it may be increased after January 1st, next, so as to be of material assistance in financing the publication of the JOURNAL.

It is greatly to be hoped that available funds can be provided to increase the number of issues of the JOURNAL to twelve each year, as there is ample

excellent material to fill the pages of a regular monthly JOURNAL. If the members of the Society are willing to accept a reasonable increase in dues, and if some additional income from advertising becomes available, it appears that the accumulated deficit can be gradually wiped out and the issuance of twelve numbers of the JOURNAL per year can be assured.

In order to establish a definite policy in a matter concerning which there has been some question recently, I recommend that all papers which are presented at any meeting of the Society become the property of the Society for first publication in its JOURNAL, unless released for publication elsewhere by the editorial board.

Respectfully submitted,

R. W. THATCHER, *Editor.*

The report was received with the thanks of the Society and the approval of his recommendation that papers read at the annual meeting become the property of the Society unless released by the Editorial Board.

Dr. C. V. Piper was called on for the report of the Committee on Cooperation with the National Research Council. Dr. Piper made a few remarks regarding the working of the National Research Council and introduced Dr. J. G. Lipman, the new chairman of the committee.

Dr. A. G. McCall made a brief report for the sub-committee of the National Research Council on Salt Requirements of Plants.

Dr. C. V. Piper reported briefly on the Pasture Project being handled by a sub-committee of the National Research Council.

The entire report of the Committee on Co-operation with the National Research Council was adopted. (To be published later.—Editor.)

The report of the Committee on a national organization of agronomy students was presented by Prof. Parker. The report was received and the committee continued.

Editor Thatcher spoke briefly of the need for an increase in dues and it was moved and carried that the dues be increased to five dollars—the By-Law of the Society specifying dues to be changed as follows:

By-Law (1)—"The annual dues for each active and associate member shall be $5.00 payable on or before March 1."

It was moved and carried that By-Law (2) be modified to read as follows:

By-Law (2)—"Any member in arrears on March 1 for dues for the current year, shall be dropped from the rolls of the Society. Reinstatement to membership may be accomplished without action by the Society upon payment of such arrears."

The proposed revisions of the Constitution as given in the Secretary's report were read.

It was moved and carried that the proposed new articles of the Constitution as proposed be adopted, the Executive Committee to interpret the articles and provide for the carrying out of the provisions, the changes to take effect next year at the annual meeting.

It was moved and carried that the American Society of Agronomy affiliate with the Federation of Biological Societies.

President Call spoke on the matter of the place of the annual meeting and told of the results of his correspondence with officials of Land Grant Colleges. The selection of the place of meeting was left in the hands of the Executive Committee.

It was moved and carried that a special committee of five be appointed

to wait on the Secretary of Agriculture to request the assistance of the Department in the endeavor of the American Society of Agronomy to bring about the registration of crop varieties.

It was moved by Dr. E. O. Fippin and carried that the Executive Committee report at the next annual meeting on the practicability of arranging a paper, by one of the older agronomists, of broad outlook, either in connection with or independent of current symposia, giving a broad survey of a practical phase of agronomy showing the status of the subject in the research work of the country, its ramifications into adjacent scientific and economic fields, the apparent major attainments and the points wherein knowledge is missing or deficient, together with suggestions of ways in which there can be practical co-operation between the workers at different stations in promoting broad, well balanced progress in the knowledge of the subject in hand.

Prof. Geo. Roberts reported that the AUDITING COMMITTEE had examined the books of the Treasurer and found them correct.

The report was adopted.

Prof. C. A. Mooers reported the following nominations for officers for the next year.

President—Director S. B. Haskell, Mass. Agr. Expt. Sta., Amherst, Mass.

First Vice-President—Professor M. F. Miller, Univ. of Missouri, Columbia, Mo.

Second Vice-President—Professor Emil Truog, Univ. of Wisconsin, Madison, Wis.

Secretary-Treasurer—Dr. P. E. Brown, Iowa State College, Ames, Iowa.

Representative on Botanical Abstracts, 4 years—Dr. H. K. Hayes, Univ. of Minnesota, St. Paul, Minn.

Representative on Committee on Co-operation with the National Research Council, 5 years—Professor C. W. Warburton, Bureau of Plant Industry, Washington, D. C.

Representative on the Council of the American Association for the Advancement of Science, 1 year—Professor W. L. Slate, Jr., Connecticut Agr. Experiment Sta., Storrs, Conn.

The report of the committee was adopted and the Secretary instructed to cast a unanimous ballot for the officers named. They were accordingly declared elected.

Dr. Piper reported for the COMMITTEE ON RESOLUTIONS as follows:

Resolved: That the thanks of the Society be extended to the management of the New Ebbitt Hotel for the accommodations extended to the Society in holding its 15th annual meeting; and that to Prof. C. W. Warburton be extended the thanks of the Society for the aid given and the trouble taken to make the meeting a success.

Resolved: That the Society extend its thanks and appreciation to the officers of the past year, particularly for the painstaking and effective service rendered by its Secertary, Dr. P. E. Brown, and for the energy and enthusiasm put into the work by its President, Prof. L. E. Call, and its Editor, Dr. R. W. Thatcher.

Resolved: That the Society express its thanks to Dr. F. E. Bear for the logical and efficient way in which he developed the Symposium on Phosphorus and to Dr. W. C. Etheridge and Dr. H. H. Love for the very enjoyable programs arranged for the Symposia on Teaching Methods and on Experimental Error.

Upon motion these resolutions were adopted.

It was moved and carried that two committees be appointed, one to continue the study of the teaching of crops and the other the teaching of soils.

Morning Session, Tuesday, November 21, 1922.

9:00 A. M.

Symposium on the Improvement of Agronomy Teaching.

Leader: Dr. W. C. Etheridge.

Report on the Progress in Standardizing the Elementary College Course in Soils, Prof. P. E. Karraker, University of Kentucky, Lexington, Ky.

Report on the Progress in Standardizing the Elementary Course in Field Crops, Dr. W. C. Etheridge, University of Missouri, Columbia, Mo.

The Organization of an Introductory Course in Soils and the Extent to Which it Should be Placed on the Basis of Pure Science, Dr. H. O. Buckman, Cornell University, Ithaca, N. Y.

The Relation of the Elementary College Courses in Field Crops and Soils to Those Offered in Smith-Hughes Schools, Prof. W. L. Burlison, University of Illinois, Urbana, Ill.

Read and discussed by Prof. M. F. Miller, University of Missouri, Columbia, Mo.

Comparative Grades in Field Crops Courses, Prof. T. K. Wolfe, Virginia Polytechnic Institute, Blacksburg, Va.

Laboratory Instruction in Field Crops, Prof. John H. Parker, Kansas State Agr. College, Manhattan, Kansas.

Tuesday Afternoon Session, November 21, 1922.

2:00 P. M.

Symposium on the Application of Statistical Methods to the Results of Field Tests.

Leader: Dr. H. H. Love.

The Importance of the Probable Error Concept in the Interpretation of Experimental Results, Dr. H. H. Love, Cornell University, Ithaca, N. Y.

The Service of Statistical Formulæ in the Analysis of Plot Yields, Dr. J. Arthur Harris, Station for Experimental Evolution, Carnegie Institution, Pittsburg, Pa.

Controlling Experimental Error in Nursery Trials, Dr. H. K. Hayes, University of Minnesota, St. Paul, Minn.

Some Limitations in the Application of the Theory of Probable Errors to Field Experiments, Prof. S. C. Salmon, Kansas Agricultural College, Manhattan, Kansas. (Read by title only.)

Analysis and Interpretation of Data Obtained in Comparative Tests of Potatoes, Dr. C. H. Myers and Mrs. F. R. Perry, Cornell University, Ithaca, N. Y.

Replication in Relation to Accuracy in Plot Tests, Prof. Robert Summerby, Macdonald College, Canada.

Competition as a Source of Error in Corn Yield Determinations, Prof. T. A. Kiesselbach, University of Nebraska, Lincoln, Neb.

Meeting adjourned.

P. E. Brown, *Secretary.*

PROGRAM FOR THE BOSTON MEETING OF THE SOCIETY.

Under the direction of Dr. B. L. Hartwell, there has been arranged as the program for a day's session of the Society in affiliation with Section O of the American Association for the Advancement of Science, at Boston, on December 29, 1922, a symposium entitled "Soil Toxicity in its Relationships to Economic Crop Production." The symposium is to consist of twenty-minute presentations of the several aspects of the problem indicated below, followed by general discussions; with the understanding that the complete papers may be submitted for publication in this JOURNAL.

The general topics to be presented in the symposium are as follows:

GILE, P. L., Washington, D. C. Methods of Diagnosing Toxicity. Kinds—detection and measurement—dosage or economic treatment prescribed from measurements by different methods.

HOFFER, G. N., Indiana. Accumulation of Aluminum in Plants and Its Probable Relation to Susceptibility to Disease. Influence of toxic soil conditions on injury associated with pathogenic organisms.

KELLEY, W. P., California. Specific Toxic Factors Met With in Alkali Soils. Application also to soils of humid climates—chlorosis—overliming—excessive concentration of fertilizer salts.

LIVINGSTON, B. E., Maryland. Effects of Toxic Soil Conditions on Physiological Disturbances of Crops. Botanical aspects—absorption—clogging by colloids—ecological relations—influence of rate of transpiration.

MCCALL, A. G., Maryland. Influence of Acidity Itself on Plant Growth Without Regard to Other Factors. On the presence of deleterious concentrations in soils—resistance of different crops to acidity itself.

MORSE, F. W., Massachusetts. Influence of Plane of Nutrition on Susceptibility to Injury from Toxic Concentrations. Anti-toxic or antagonistic effect of plant nutrients.

SCHREINER, O., Washington, D. C. Organic Toxic Substances. Recognition—elimination—green-manure relations.

THATCHER, R. W., New York. Effect of Crops on Each Other. Grown togther or in succession—toxicity as modified by crops—beneficial soil treatments.

TRUOG, E., Wisconsin. Relative Immunity of Different Crops to Toxic Soil Conditions. Chemistry involved.

WHITING, A. L., Illinois. Inorganic Toxic Substances. Aluminum, etc.—associated bacterial relations—biological conditions associated with temporary toxicity.

INDEX

Date of issue.	Date of issue.	Date of issue.
3.6.[illegible]		
7.4.60		
20.6.64		

MGIPC—S5—38 AR/54—7-7-54—7,000.